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Perspective

External Environmental Costs of Solid Biomass Production against the Legal and Political Background in Europe

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Abstract: Over the years, the generation of energy from renewable sources (RES) has gained importance because of a number of reasons. One of the most powerful arguments in favor of the development of RES is the deteriorating natural environment, and consequently worse human health, due to energy generation from fossil fuels. The extent of this impact can be determined by identifying external costs. In a circular economy, the estimation of external costs attracts much attention in both the literature and practice. The aim of this article was to review and analyze the latest literature (2018–2022) covering the external environmental costs of solid biomass production for energy purposes in the context of the political, legal and methodological debate concerning the production of energy from biomass, and to make an effort to estimate the external costs of producing energy from solid biomass grown for energy purposes. The methods used in the article were as follows: a comparative analysis of the collected references; a dogmatic analysis of the contents; a meta-analysis of results published in the literature; and an analysis of frequency occurrence and co-occurrence of the key words. The average external environmental costs of the production of biomass for energy purposes were calculated at 20.35 EUR Mg^{-1} d.m. with a 95% confidence range of 13.86–26.85 EUR Mg^{-1} d.m. (adjusted to EUR 2021). These values were estimated from the meta-analysis, which was statistically significant despite a rather small sample of studies submitted to the analysis. The European Union (EU) policy and the law passed under this policy over the past 15 years have supported and stimulated the development of renewable energy resources. The political and legal situation arising after Russia's invasion of Ukraine and the energy crisis has forced decision-makers to revise the previously developed assumptions, although reducing greenhouse gas emissions in Europe and achieving climate neutrality remain important targets. It is also crucial to make Europe independent from Russian fossil fuels, for example by accelerating activities aiming to raise the production of renewable energy. In this context, the production of solid biomass for energy purposes gains importance, especially since it can be produced locally and become an important contributor to national energy security. Hence, the external costs of the production of biomass and energy from sources other than fossil fuels should be analyzed. Such analyses are significant because they show the actual costs of renewable energy production, including its profitability and competitiveness in relation to fossil fuels.

Keywords: solid biomass production; environmental valuation; energy law and policy

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1. Introduction and Concept of the Problem

Bioeconomy as a strategy for the development of Europe has long been advocated for. The first strategy of this kind was adopted in 2013 [1]. According to this document, the European bioeconomy was essential for attaining neutrality as regards carbon dioxide emissions in many sectors, including the energy sector. Bioenergy, i.e., energy from biomass, has achieved the highest share among all renewable resources (RES) in the EU, and it is expected that RES will become the key element of the energy basket by the year 2030.

An updated strategy, adopted in 2018 [2], included such aims as limiting the dependence on non-renewable resources, e.g., fossil fuels, or promoting bioenergy as a key element of the EU energy basket, to be achieved by 2030. Moreover, it was highlighted that the bioeconomy was an important contributor to social development by offering new jobs, especially in rural areas.

The bioeconomy has also been implemented through the European Green Deal 2019, in which it was indicated that the energy system's transition that envisages a supply of clean and safe energy from RES is one of the ways of attaining climate neutrality. On the wave of these changes, the Baltic states confirmed that they would have achieved the use of 100% renewable energy sources in energy production and would have implemented a zero-emission economy by 2050 [3].

The shift to a low-emission economy requires that the EU undertake mutually correlated activities in various areas, including policies (strategies), economy and law. This is compliant with Article 194 of the Lisbon Treaty on the functioning of the EU, which introduces a legal base for the domain of energy, according to shared competences between the EU and its member countries, stating that for the sake of establishing and operating the internal market and for preserving and improving the environment, and in order to sustain the spirit of solidarity between the EU member states, the aim of the EU energy policy will be to "(i) ensure the functioning of the energy market; (ii) ensure security of energy supply in the Union; (iii) promote energy efficiency and energy saving and the development of new and renewable forms of energy; and (iv) promote the interconnection of energy networks" [4].

Energy systems all over the world are undergoing transformation. The main reasons are technological progress, institutional changes, depletion of fossil fuel resources and climate change [5]. In Europe, the energy crisis caused by Russia's invasion of Ukraine has strengthened the need and pace of this transformation. At the local level, the development of distributed energy sources has necessitated the reorganization of centralized energy systems. Integrated Community Energy Systems (ICESs), whose aim is to connect distributed energy sources and to engage local communities, seems to be a response to these needs [5]. Local energy systems not only support the development of energy self-sufficiency but are also part of a larger energy system [5].

Energy transformation proceeds along new pathways. These new pathways are created on the basis of existing or novel resources, associated also with the social aspect. Therefore, social approval and the creation of new pathways can be considered as mutually reinforcing processes, which are of key importance for energy transformation. A study by Panori et al. [6] focused on the use of agricultural biomass (or agribiomass) as a renewable energy resource. The results suggested that the creation of new knowledge served as an impulse for general perception while the existing knowledge and previous experience raised the willingness to install heating systems based on agricultural biomass. In terms of shaping the market, social acceptance was fortified owing to the acquisition of agribiomass and technologies by local farmers and producers. Cost savings and positive local impacts significantly supported decisions to launch new investment projects.

Social engagement in energy transformation has led to the emergence of renewable communities. Renewable communities are bottom-up initiatives which invest in 'clean energy' in order to satisfy consumer demands and environmental goals, and thus—often unwittingly—foster the dissemination of renewable energy sources [7]. Support for renewable communities is important in the context of energy poverty, especially in rural areas. The alleviation of energy poverty and implementation of newer technologies is a multidimensional process [8], defined within three areas of energy technology implementation in many environments. The first one involved the rethinking of the term 'impact'; the second one was related to the recognition of differences between practitioners' perception and the reality of end-users, and the promotion of a shared approach among all key stakeholders in an energy value chain or system. This inclusive approach promotes a greater role for local communities and is a better manifestation of their actual needs.

The contribution of society and individual citizens as a party engaged in energy transformation, and referred to as a renewable energy community, has been one of the key factors influencing the development of renewable energy technologies [9]. Renewable communities, regardless of having been initiated by citizens, the private sector, or municipalities, have contributed to the creation of an added value following from the growth of renewable energy. Such added values have been assigned to three areas: economic, social and environmental. Economic values include affordable prices of energy, new products and services connected with renewable energy, and new jobs. Social values comprise the inclusion of people from different socio-economic spheres and a sense of togetherness. Environmental values are the reduction of carbon emissions, new technologies and an environmentally friendly lifestyle.

Renewable communities have acted as a catalyst for social innovations as well as the engagement of citizens in energy generation measures and the use of local resources. The literature contains reports on studies which describe business models adopted by renewable communities [9,10]. Ceglia et al. [10] showed that in some renewable community models, the economic profitability of systems based on woody biomass can be higher, being also able to add to the increasing share of other renewable technologies using local resources, for example photovoltaic panels.

Energy transformation can be achieved not only through the implementation of renewable energy sources, but also through the use of new concepts and management solutions in the power sector. Renewable communities, for example, have encouraged the maximum self-consumption of energy generated from renewable sources, which is yet another factor enhancing energy efficiency and reducing the cost-consumption of resources [11]. Chaudry et al. [12] demonstrated that a high level of prosumership in energy communities may bring about technical and economic benefits, economic profitability, a maximum reduction of greenhouse gas emissions by 35%, and the maximum share of self-consumption increasing by 61%, relative to the much lower levels achieved where no prosumership was involved.

Several important issues arise against this backdrop of the identified bioeconomy goals, energy policy and energy transformation towards a zero-emission economy. There is the problem of issuing appropriate strategic documents, which will allow the implementation of suitable measures. There is also the question of the technical, economic, socially acceptable, and environmentally friendly feasibility of the planned measures aiming to achieve the goals listed above. Finally, there is the question of methodology, which is the key topic of this article. A selection of adequate methods, which will allow us to make multi-criterial assessments of both planned and launched solutions and their evaluation is extremely important. The implementation of new technologies will also have a strong influence on the social aspect, as it is envisaged that over 1,512,000 new jobs will be created in the sector of sustainable energy production [13].

Life-cycle assessment (LCA) belongs to the standard methodology for evaluating the impact of a system on the environment, and as such it is applicable in circular economy research. It is a multicriterial method and serves to evaluate the global warming potential (GWP), as well as many other consequences of emissions to the atmosphere, such as the depletion of the ozone layer, acidification, smog, solid particle emissions, or the depletion of natural resources, for example water, land, fossil fuels and abiotic elements. Importantly, the LCA methodology is well-understood in practice. Its development and implementation in other areas of sustainable development, i.e., environmental life-cycle assessment (LCA), social life-cycle assessment (SLCA) and economic life-cycle costing (LCC), enable the performance of multicriterial analyses.

The target of economic estimates with the LCC approach is always to make an appraisal of financial costs. Since any business activity may have many positive and negative consequences, it appears particularly valid to expand the scope of economic estimates by adding environmental aspects of a life-cycle assessment (LCA), and to introduce an economic impact pathway covering midpoint and endpoint indicators in categories defined in life-cycle assessment [14]. Cost estimates are also significant for the development of any RES support policy. Cost analysis allows one to determine the type and effectiveness of financial support offered by states, which may help to raise the quantity of energy generated from RES or the supply of biomass for energy purposes.

2. Review of the Literature

For over twenty years now, theoreticians and practitioners have been developing and implementing a variety of methods in which environmental and economic analyses of products, technologies and systems have been combined [15]. Methods for conducting life-cycle assessment (LCA) and life-cycle costing (LCC) have been integrated in various ways. Hybridized frameworks for such mergers were expected to provide decision-makers with a complex method to navigate an environmental and economic analysis. The key features are as follows: an integrated structure that enables the integration of many types of LCA and LCC, the inclusion of many perspectives for arriving at decisions, a decision-making process aimed at selecting different methods of an analysis, and the integration of the system and procedures concerning the conventional calculation of life-cycle costs (CLCC) and environmental life-cycle costing (ELCC), as well as total costs, including the external 'ecological costs' of the impact of LCA on the environment.

Da Silva, Barbosa-Póvoa [16] underlined that solving environmental problems within a supply chain is a challenge, where one of the biggest obstacles is to quantify the impact on the environment in an understandable and communicative manner. Quantification in chemical units has been conducted frequently, but it does not always let decision-makers understand how supply chains influence the environment. In this respect, quantification in monetary units can be advantageous. Hence, it is necessary to develop a tool supporting the making of decisions involved in the designing and planning of supply chains that will take into account the monetization of environmental impacts. This should be achieved by exploring the most popular monetization methods.

The literature provides examples of a debate going even further than that, up to the price of the sustainable development of a product or service [17]. The notion of an environmental price was a follow-up of the recommendations of the Sustainable Development Goals, as well as a response to the suggestion made by the UN Secretary General's High-Level Panel on Global Sustainability (GSP) to include social and environmental costs in the pursuit of a sustainable economy. To enable the inclusion of environmental and social costs, known as external costs, it is necessary to identify and estimate them.

An external cost appears when the production or consumption of a product or service incurs a cost for a third party [18]. An example of external effects in an economy is air pollution generated by the production of electricity from fossil fuels. Pollution causes considerable social and environmental losses, e.g., short- and long-term exposure to particulate matter (PM) as well as increased mortality and morbidity, which indicates the need for the constant improvement of the quality of air [19]. A study of Ko and Kyung [20] confirms that air pollution has adverse effects on different organs in the human body, mainly the respiratory system, increasing the risk of death even when present at concentrations lower than the binding national threshold levels. For example, exposure to particulate matter with particles of <2.5 μm in diameter ($PM_{2.5}$) is linked to lung cancer and correlated with the exacerbation and development of asthma. It has been demonstrated that exposure to nitrogen dioxide (NO_2) is associated with higher mortality among patients with idiopathic pulmonary fibrosis, raising the risk of contracting infectious diseases such as pneumonia, bronchitis and tuberculosis. Moreover, the emerging evidence confirms the relationship between air pollution and the transmission of, susceptibility to, and mortality due to coronavirus 2019. Treatment of such illnesses represents external costs. A positive and considerable effect of the increasing contribution of renewable energy above 28.22% on reducing air pollution has been confirmed by Zhang et al. [21].

Based on a review of the development of a life-cycle sustainability assessment (LCSA) and recent achievements [22], it can be concluded that the method was employed to evaluate energy production in one third of the reviewed works, especially in the context of CO_2. Thus, it seems that a discussion on the transfer of burdens caused by climate change to other noxious effects on the environment features in the literature, and that the need to take into account economic and social implications in analyses is acknowledged.

In a study called Climate change and monetary policy in the euro area [23], it was concluded that external environmental costs of an economic activity still could not be properly estimated by financial markets. An excessively low price of carbon dioxide emissions, insufficient data on the exposure to climate risk as well as the lack of widespread certification of ecological activities remain as serious obstacles to efficiently making a market evaluation.

A monetary appraisal of the effect of a product or service on the environment can be performed according to different methods, e.g., abatement cost, averting behavior, budget constraint, contingent valuation, damage cost, price market, willingness to pay, and willingness to accept, based on which the monetary estimation coefficients are determined [24]. A review of monetary valuation in life-cycle assessment titled State of the art and future needs, showed that the accessibility of monetary assessment coefficients is highly varied within different categories of the LCA impact analysis. Some impact categories are analyzed on a wide scale and therefore monetary assessment coefficients can be found in different types of references (e.g., climate change, depletion of the ozone layer), while other impact categories (e.g., eutrophication, land use) have not been researched so thoroughly and few monetary assessment coefficients are available. Moreover, the information on details of the basic methodology employed in the calculation of values of a monetary assessment coefficient is sometimes missing, while values of monetary assessment coefficients differ among the methods up to three orders of value.

Over the years of discussions on external environmental costs, many methods have been developed to monetize impacts on the environment based on results of life-cycle assessments. The most common are Ecotax, Ecovalue12, EVR, EPS, the Environmental Prices, Stepwise2006, LIME3, Trucost and the MMG-Method. A detailed specification and comparison of these methods in 18 impact categories can be found in [25], titled Comparison of different monetization methods in LCA: A review. That analysis showed that monetary values for the same impact category typically ranged between two orders of values for the evaluated methods. The above study also analyzed qualitative factors that influence the monetary values of indicators in particular impact categories and determined that the highest value was achieved by income per capita, and consequently by the geographical reference. Determination of the importance of an impact category yielded different results when applying different methods; for example, Stepwise and Ecovalue attributed over 50% of the damage per capita to climate change, while EPS and LIME3 assigned about 50% to the depletion of mineral and fossil resources.

In a circular economy, the question of an appraisal of external costs attracts attention both in the literature and among practitioners. The subject literature underlines the importance of the development and implementation of methods for the calculation of life-cycle costs from the viewpoint of a life cycle or the flow of a product/material, which proves that this method can be helpful in the management of circular economy enterprises. The results obtained with the use of LCC and external costs indicate economic benefits and a reduction of CO_2 [26].

The vast majority of the studies reviewed by D'Amato, Gaio [27] employed analyses of the environmental life-cycle LCA (86%), while 10% used mixed methods; specifically, three studies applied LCC, one—SLCA, and another three used other methods. LCC including externalities has been developed as a method for an assessment of building investments and continues to be applied and further developed in this sector of economy [28].

Integration of life-cycle assessment and life-cycle costing seems to be most advanced in areas of the design and construction of buildings and in civil engineering, but there are still some challenges to be faced. They include monetization of the environmental impacts, a larger variation of economic data than that of environmental ones, and differences between environmental and economic data. These challenges can be transformed into opportunities to develop more complex methodological approaches. A combined approach makes it possible to lessen the impact on the environment and economy caused by planned developments, products and services, which can be assessed quantitatively and compared, owing to an improved assessment of potential compromises [29].

LCC analyses including externalities have also been made for chemical products [30]. The internalization of external environmental costs through the economic effects of a production enterprise is significant in view of the degradation of nature due to any production activity. Despite numerous discussions and studies concerning this sphere, we still lack methods for the internalization of external costs through a profit and loss account although it is possible to come across reports on the internalization of externalities, for example in a petrochemical company [31].

The environmental externalities that are most often analyzed are related to the emissions of greenhouse gases (60.32%), followed by air pollutants (39.16%). The developed methods focus on production systems, enabling managers to gain a holistic view of how production systems work and broaden their understanding of sustainable development in production activities. Inclusion of external costs in an assessment of the technical and economic efficiency of industrial processes is important because it can drastically change the outcome of the analysis [32].

The production of energy from biomass is a promising alternative to fossil fuels because the former is available in most parts of the world and ensures a large flexibility of use in different forms of energy carriers. However, its price competitiveness remains difficult to evaluate because of the high variability of costs of bioenergy, which is unproportionally made up of the cost of biomass as a raw material. An analysis of data originating from 45 countries and related to five types of lignocellulose biomass, i.e., from a managed forest, wood energy crops, grass energy crops, agricultural residues and forest residues, demonstrated that the costs of biomass from forest residues and from agriculture were the lowest among all the analyzed types of biomass. No significant difference was observed between the costs of growing energy crops—grasses, woody energy plants or biomass from a managed forest; on the other hand, it was found that biomass grown in Latin America was much cheaper [33].

Observations of the energy market reveal the fact that for many years prices of energy generated from fossil fuels have been lower than prices of energy from renewable sources in the whole world. These market prices, however, did not take into account the environmental or social costs of energy and ignored the negative external consequences for public health and the environment [34].

Internalization of costs due to environmental and health losses in prices of electric power would raise the costs of energy production from fossil fuels, having a more profound impact on the environment. It is a useful measure to indicate the actual energy costs and it makes fossil fuel energy less competitive than energy generated from renewable sources. Hence, the results of calculations of external costs can be employed to evaluate different types of energy generation technologies and to select cleaner technologies [18].

Nevertheless, to properly estimate costs of energy production from RES, it is necessary to determine costs in a life cycle, i.e., LCC, and to include externalities in these calculations. According to Lu, Wang [3], the transition to RES brings about social benefits for the EU member states. These authors explained how subsidies to RES corresponded to reduced external costs of energy generation and specified important political implications for these countries. They also suggested how benefits from supporting RES could be evaluated. Dynamic discussions and attempts at evaluating external costs in monetary units were reflected in the literature published in the period 1999–2017, and especially in the first decade of this time period: [35–46], several review papers were issued, e.g., [24,25,47]. Amadei, De Laurentiis [24] underlined that many studies which employ monetary assessment units quote few references, on top of which some are more than 10 years old. The aim of this paper has been to make a review and an analysis of the latest literature (2018–2022) dealing with the external environmental costs of solid biomass production for energy purposes against the background of the political, legal and methodological debates concerning the production of energy from biomass. The aim was to show the current status and developments in that field; an additional goal was to assess the external costs of production of solid biomass for energy purposes.

3. Materials and Methods

The input analytical material for the study consisted of 524 scientific original papers, reviews and perspective articles, reports, and strategies, of which 110 publications from 2018 to 2023 were selected. The initial selection of the papers was based on key words found in the Scopus and Web of Sciences databases, that is biomass for energy, external cost, externalities, monetary valuation and monetization. Next, the papers were analyzed and selected for their concordance with the assumed aim, analyzed time period and scope of the study.

The first step of the study was to make a comparative analysis of the collected references. In relation to the legal analysis, the method of a dogmatic analysis of the contents of binding legal regulations and proposed strategies regarding RES was employed.

The second step consisted of a meta-analysis of the literature data conducted for the external costs of production of 1 Mg d.m. converted to the euro according to the currency exchange rate in 2021. The outcome of the analysis was composed of average values of the external costs for independent variables in a variable model. The analysis covered 8 studies and was conducted using STATISTICA 13.3 package (TIBCO Software 2017).

Finally, the selected papers were analyzed in terms of the frequency of occurrence and co-occurrence of the key words. The analysis of the frequency with which the key words appeared was presented as a Pareto diagram, whilst the analysis of their co-occurrence was displayed in the VOSviewer software program, both covering the 110 publications finally chosen for the study. Based on the frequency of occurrence of the particular key words, a network of the key words was plotted, with the key words grouped into clusters according to their co-occurrence [48]. The analysis included 409 key words and was carried out up to at least three instances of co-occurrence. The key words were assigned weights, and the ones which appeared more often were represented by larger circles and marked with bigger fonts on the map. Colors of the elements were used to mark the clusters in which a given key word appeared. Lines between the words represented links, and distances between any two words in the visualization were proportional to the degree of affinity of the key words in the links of a publication. The closer they were, the stronger the relationship and more frequent their co-occurrence. The analysis was run using a technique of grouping. The second analysis of co-occurrence was expanded by including scores–average publication year, in order to determine the temporal variability of the presence of key words.

4. Results and Discussion

4.1. The Legal and Political Situation in Europe

Implementation of the mechanisms involved in the execution of the policy of strengthening the transition to renewable energy can be divided into a few periods (Figure 1). The first one spans the years 1998–2009, when the first energy package was launched alongside the issuing of the Directive on Renewable Energy Resources (RED-I) [49]. The second period is the years of the implementation of that directive, i.e., 2009–2018. The latter is the year when the second directive was passed, that is RED-II [50]. The third period is delineated with the dates when RED-II came into life to the outbreak of the war in Ukraine, i.e., 2018–2022. The latter event caused many changes in the way we approach energy and supply chains. Significant changes have been observed and important debates have been held in this area since 2022.

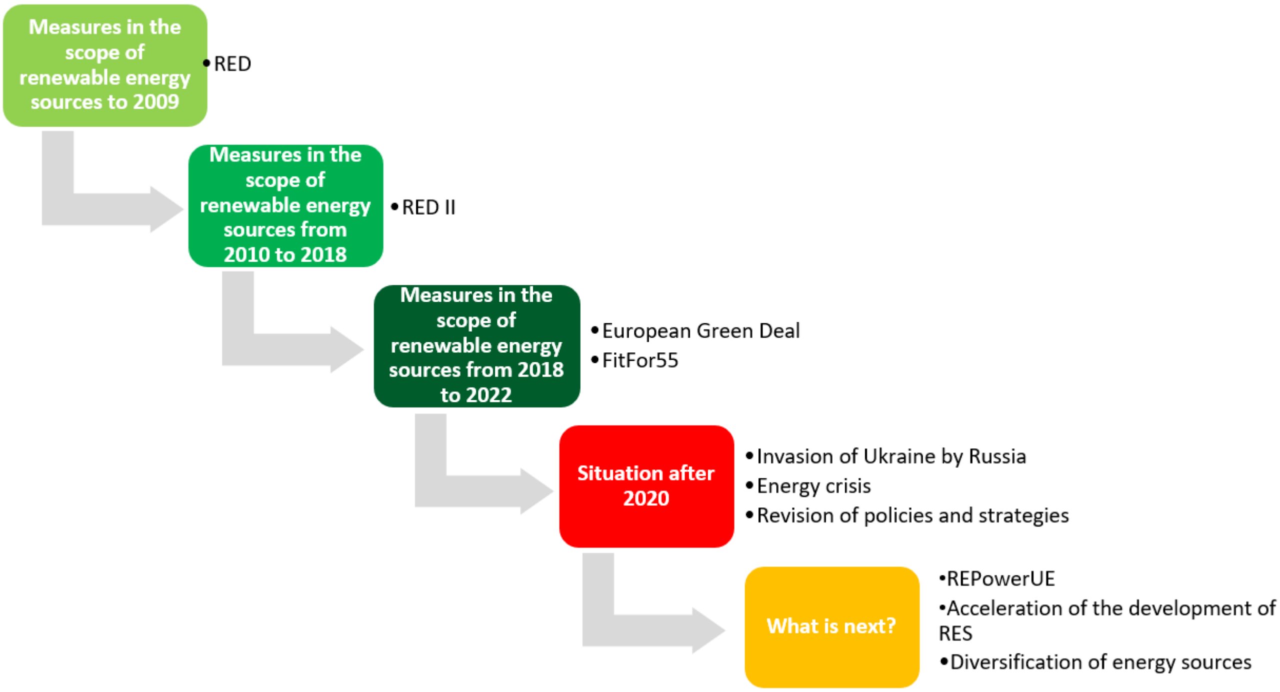

Figure 1. Diagram illustrating changes in political and legal concepts.

4.1.1. The 1998–2009 Period

The period 1998–2009 was a time when the law and strategies concentrated on creating a common energy market and the principles relating to its implementation and liberalization were created. By showing this period as a separate one, we were able to achieve a significant goal, such as demonstrating the lengthy duration of the process leading to the initiation of legal changes that would enable the transition away from the coal-based energy generation.

In that period, the main aim of amendments in the law was to liberalize the market; meanwhile, environmental issues were neglected. It was not until the last years of that decade that the discussions on the protection of nature and climate were reflected in the strategies and regulations found in the EU directives. Acknowledging and addressing issues related to the need to increase the production of energy from renewable sources represented the first instance of a real, large-scale measure taken for the sake of climate. Thus, this first, rather lengthy period is worth attention because climate-related questions, including a higher share of renewable energy, would feature more and more profoundly in the strategies and laws developed afterwards. An analysis of this first period clearly displays the initial goals of the EU energy policy. The first directives related to the liberalization of energy markets were passed in 1996 (about electric power) and 1998 (about natural gas), i.e., Directive 96/92/EC [51] and Directive 98/30/EC [52]. The EU member states were supposed to have these directives implemented by 1998 regarding electricity and by 2000 regarding natural gas (Table 1).

The aim of the above directives was to set a timetable for the gradual opening of the markets and the minimum degree of market openness at each step. Unfortunately, the implementation of these regulations did not bring about the expected results in terms of the opening of EU markets. The essence of the proposed solutions was to separate the transmission and distribution from such competitive activities as production and supply of energy [53]. The achieved division regarded only accountancy and management in the electric power sector, and accountancy alone in the natural gas market. The regulations contained in the directives also started the TPA (third-party access) rule, that is a non-discriminating access for third parties, which gave business undertakings the right to access transmission and distribution network facilities in electricity markets in two ways.

However, none of these legal solutions functioned properly and the member states preferred to rely on the imperfect regulatory approach. The subsequent laws during that period were passed in 2003, including the Regulation (EC) No 1228/2003 of the European Parliament and of the Council of 26 June 2003 [54], and the proposal for a directive of the European Parliament and of the Council amending Directives 96/92/EC [51] and 98/30/EC [52]. These solutions strengthened the liberalization of the energy market. Since then, industrial consumers and member states have had the right to choose freely their gas or electricity supplier from a broader circle of competitors. These changes had been enforced by the far from satisfactory progress in the integration of energy markets pursuant to the previously binding law. The Commission concluded that although the first phase of opening these markets led to visible results, the lack of integration of national energy markets remained the most important problem [55]. Sensing the need for further liberalization of energy markets, new legal solutions were passed in 2009. In April 2009, the third energy package was adopted, and the objective was to achieve further liberalization of internal markets of electricity and natural gas. It amended the second package and became the foundation for the process of creating a common, internal energy market. While building a uniform, liberal market of energy, a need to modify the ways energy was generated and the types of energy produced was acknowledged, which was associated with climate protection, especially the reduction of greenhouse gas emissions. The above actions led to the adoption of relevant EU directives setting up goals for the EU member states. The directive on RES, adopted on 23 April 2009 [49]—RED-I—endorsed a mandatory target of a 20% share of energy from RES in the community's total energy consumption by 2020.

4.1.2. The 2010–2018 Period

After RED-I came to life, there were numerous debates and analyses concerning the European Union's strategy for the energy union. Examples are two communications from the Commission: [56,57]. An outcome of the above discussions was the implementation of subsequent changes in the years 2010–2018, which for example applied to the production of energy from renewable resources. These modifications contributed to the development of a bioeconomy strategy, which in turn belonged to a circular economy. In this scope, significant changes were made in 2018 by adopting the Directive of the European Parliament and of the Council 2018/2001 of 11 December 2018—RED-II [50] (Table 1). These legal regulations annulled directive RED-I by launching the common framework for promotion of energy from RES and setting up a new community target of at least 32% of renewable energy in the final gross consumption of energy in the European Union by 2030. This meant extending the time period by 10 years in comparison to directive RED-I, while the target share was raised by 12 per cent. The achievement of the goal set in RED-II would have decreased the emissions of greenhouse gases by at least 40% by 2030 relative to the levels in 1990. The implemented monitoring of achieving the targets set in the above directives has shown how these targets have been pursued. In 2018, twelve EU member states had already achieved a share of renewable energy above the target set for year 2020. Eleven other EU member states had reached or exceeded the average per cent target set in RED-I for the years 2017–2018. However, five countries (France, Ireland, the Netherlands, Poland and Slovenia) failed to achieve this goal [58]. It is worth noting that the share of renewable energy in the EU energy basket reached nearly 19% in 2018 (18.9% for EU-27). According to the above report, investments in renewable energy were increasingly driven by the market, and the contribution of public subsidies was decreasing, especially into new investments. This was a consequence of the considerable reduction in costs incurred by renewable energy technologies and decreasing the subsidies owing to more competitive support systems, for example numerous zero- or low-cost initiatives in several European countries. Most of the EU member states achieved the set goals, but three (Belgium, France and Poland) faced a serious risk of failure. Moreover, two member states (the Netherlands and Luxembourg) were moderately exposed to the risk of failing to reach the targets [5].

4.1.3. The 2018–2022 Period

In June 2019, the fourth energy package was adopted, now composed of one directive [59] and three regulations (including the Regulation of the European Parliament and of the Council (EU) 2019/941 of 5 June 2019 [60] (Table 1). New solutions concerning the market for electricity were introduced within the above legal framework, with the intention to satisfy the demand for RES energy and to attract new investments. Incentives for consumers were envisaged as well as a new limit below which electric power plants were eligible for subsidies from the mechanism of production capacity. In addition, the member states were obligated to prepare emergency plans in case of an electricity crisis.

In December 2019, in view of the need to verify the existing strategies, the European Commission issued the Communication From The Commission European Green Deal COM (2019) 640 final [61]. This was the basic strategic document setting up the directions for the measures undertaken by the EU states in order to achieve climate neutrality, in which the areas in which action is necessary and specific aims that should be achieved are indicated. Following this strategy, the documents Fit for 55 and REPowerEU were issued [62].

In July 2021, several communications were published pertaining to the future solutions for the development of the Community's economy. They included the Communication From The Commission To The European Parliament, The European Council, The Council, The European Economic And Social Committee And The Committee Of The Regions Fit for 55: delivering the EU's Climate Target for 2030 on the way of climate neutrality [62]. The goal of the Commission is to reduce emissions of greenhouse gases by at least 55% and to achieve climate neutrality of Europe by 2050. Moreover, within the measures undertaken under the European Green Deal umbrella (reaching climate neutrality by 2050), in July 2021, the Commission proposed to amend the RED-II Directive concerning renewable energy sources so as to adjust its goals concerning renewable energy to new climate goals. The Commission proposed to raise the existing target on renewable energy up to 40% by 2030, and promoted the use of such renewable fuels as hydrogen in industry and transport in the specification of additional targets [63]. The conclusion in the Directive of the European Parliament and of the Council amended the Regulation of the European Parliament and of the Council (EC) 2018/1999 and Directive 98/70/EC of the European Parliament and of the Council [64]. The overall objectives of the amendments to RED-II were to achieve the elevated use of RES energy by 2030, to support the better integration of the energy system, and to contribute to the achievement of climate and environmental goals, including biodiversity preservation and solutions to inter-generational problems connected with global warming and the loss of biological diversity. The amendment of RED-II was crucial for the potential attainment of a more ambitious goal in the sphere of climate and for the protection of our environment and health, as well as for limiting Europe's energy dependence, supporting the EU's leading role in technologies and industries, creating new jobs and contributing to the economic growth. The new proposals put forth by the European Commission were associated with launching new support mechanisms in different areas of the functioning of the whole Community and the member states. The first one was the renewable financing mechanism (Regulation 2020/1294) pursuant to Art. 33 of the Regulation on Management (EU 2018/1999) and contained in the package titled Clean Energy for All Europeans. This mechanism has been valid since 2020, and the Commission is still busy implementing it.

New goals expressed in REPowerEU require additional investments of EUR 210 billion between now and the year 2027. The main objective of the mechanism was to support countries in reaching individual and collective targets concerning RES. The financing mechanism connects the states which make contributions to the financing of projects (contributors) with the ones which agree to have projects completed in their territories (receiving countries). The Commission has developed a framework for the implementation and ways of financing the mechanism, stating that member states, EU funds or contributions from the private sector can finance measures within this mechanism.

Another mechanism concerns the taxation of the generation of energy in RES facilities. With respect to this area, in July 2021, the Commission put forth a proposal to review the Directive in the matters of energy taxation (Directive 2003/96). This document contains some proposals for the adjustment to the EU's policy in the scope of energy and climate on taxes levied on energy products, promoting clean technologies, and for the removal of outdated tax exemptions and decreased tax rates, which still encourage the use of fossil fuels [65].

The above proposal was based on two pillars. First of all, the new structure of tax rates would be based on the calorific value and environmental effectiveness of fuels and electricity, and not on their quantities, as is most often the case nowadays. Secondly, the tax base proposed by the Commission was expanded by including a larger number of products and relinquishing some of the tax reliefs and reductions. In more detail, it proposed that the minimum tax rates should be based on the calorific value of each product (expressed in euro per gigajoule). This would ensure that both companies and consumers would receive clearer price signals, which would help them to make more ecological, energy-saving and climate-friendly choices. In compliance with the current legal regulations pertaining to diesel oil used as a fuel in motor engines, for example, a lower minimal rate is set than for petrol used for the same purpose. The Commission's intention is to change this. The proposal puts energy products and electric power into categories according to types of energy, and orders them according to their calorific value and environmental performance. The idea was to levy the highest taxes on fuels causing the most severe environmental pollution. In view of social goals, the European Commission also envisages that the member states will be allowed to exempt households in difficult economic conditions and struck by energy poverty from taxes on fuels for heating and on electricity. This targeted tax exemption can support and protect households in a difficult situation during the transition to RES.

Another area concerned the resources used for energy production, including solar energy, biomass and biofuels, hydrogen, offshore wind energy, and ocean tidal energy. Regarding biomass, the Directive on the promotion of the use of renewable energy (Directive (EU) 2018/2001), which is currently binding, sets up a target of a 3.5% share of advanced biofuels and biogas in the transport sector by 2030 and an intermediate target of 1% by 2025. The current threshold for first generation biofuels was maintained at 7% for road and rail transport, while obligating all member states to ensure that fuel suppliers maintain a certain share (6.8%) of low-emission and renewable fuels in fuel supplies; moreover, the scope of applicability of the EU sustainable development criteria was expanded by including the sphere of bioenergy (to cover biomass and biogas used for heating or cooling and for the generation of electric power). In July 2021, the Commission published a proposal with respect to the Directive on renewable energy sources, where the proposed target was a 2.2% share of advanced biofuels and biogas by 2030 and the intermediate goal was 0.5% by 2025, which must comply with the new targets set in REPowerEU. Potential capacities for increasing the production of biomass are discussed by Tzelepi, Zeneli [66] and Bełdycka-Bórawska, Bórawski [67].

Unfortunately, it needs to be mentioned that the above assumptions do not directly envisage any support to biomass producers, although such aid may be included in detailed guidelines. Considering the costs, what matters is not only energy production from biomass but also the stage of growing and producing biomass if it is to be a source of energy. In this regard, the following documents should be considered: European Commission Union OJotE (Ed.), Regulation 2018/841/EC (LULUCF Regulation) and Decision No 529/2013/EU (2018) Brussels) (Regulation LULUCF) [68]. They create a legal framework for the EU for the reduction of greenhouse gas emissions. Studies indicate a correlation between the use of biomass and a decrease in emissions of greenhouse gases [69]. It should be underlined that the Kyoto Protocol did not take into account agriculture and forests when considering the attainment of reduced greenhouses gas emissions (GHG). Since the climate agreement reached in Paris [70], forests have been officially recognized as contributors to the reduction of GHG emissions after 2020 (i.e., CP3 from 2021 to 2030).

Nowadays, it is underlined that biomass from forest management makes up a large share of all biomass. According to the supplementary energy efficiency directive [50], biomass-based fuels should be incinerated efficiently to obtain electric power or heat. This will enable the maximization of energy security and the reduction in emissions of greenhouse gases (GHG), reducing the release of air pollutants and minimizing the pressure on limited biomass resources [50]. Finally, a need arose for greater synergy between the circular economy and different uses of biomass, especially in view of the fact that wood can be used for the manufacture of many products with higher added value than just energy [57].

It does not seem that the subsidies to forest cultivation for forest management and reforestation can resolve the above issues, as they are principally not dedicated to energy production. This does not exclude using the above mechanism to support the growing of forests for energy purposes [71].

The understanding of the contribution of bioenergy in the future EU energy mix has strategic meaning for the achievement of climate goals. Mandley, Daioglou [72] estimated that the technical supply was able to satisfy the future total demand from the national stock of resources, sustaining the potential capacity to reduce the overall dependence of the EU on imports of primary energy by 22%. They also predicted a rise in interregional imports by 13–76% as some of the national stock of resources would be deemed unavailable due to economic reasons or excessively low quality.

Sustainable supplies of biomass can constitute 20–30% of future global and European supplies of energy, leading to a decrease in the total costs of alleviating climate change, including the removal of CO_2 from the atmosphere [73]. The cited author also identified the conditions that would allow for the obtaining of an adequate amount and quality of biomass, for example better agricultural technologies, especially for the remediation of marginal and degraded land resources. Another condition would be the adoption of priorities and political programs, especially on the EU level, that could express an integral approach to the synergy between the role of biomass in energy transformation, the adaptation to and alleviation of climate change, better agriculture and, in general, better use of land. Similar thoughts on the transfer to technologies and resources based on RES in the context of reducing GHG emissions were expressed by Kumar [74].

The implementation of bioenergy on a large scale calls for plantations of energy crops and the availability of more agricultural land. To enable the contribution of bioenergy to decarbonization, it is necessary to secure technological feasibility, although political and legal feasibility seems even more important, as it will ensure regulatory cohesion, appropriate coordination and the structuring of the market in order to satisfy the needs of various entities in different sectors, from farmers through to investors in technologies, and distributors up to end consumers [75]. In this context, the problem of competing for land to build RES facilities can be noted. A similar problem affected plantations of energy crops. This should lead to the reorientation of RES energy production to marginal land or to the implementation of solutions promoting the coupling of agricultural production and energy generation. Another step could involve reducing the use of primary biomass to the advantage of biomass from energy crops.

4.1.4. After 2022

After the Russian invasion of Ukraine, the assumptions made prior to this event needed to be verified. The EU Commission proposed new amendments (RED III and RED IV) in order to accelerate the transition to clean energy in line with a gradual decrease in dependence on fossil fuels from the Russian Federation. The EU Commission recommended the installation of heat pumps, increasing the capacity of photovoltaic systems, and the import of renewable hydrogen and biomethane so as to raise up to 45% the target concerning renewable energy sources set for the year 2030 [76]. This document asserts that renewable energy is a key element in the transition to clean energy under the European Green Deal. The current international tensions caused by the war in Ukraine waged by the Russian Federation, the overall geopolitical situation and very high prices for energy have fortified the need to accelerate the improvement of energy efficiency and implementation of solutions for renewable energy use in the European Union, in order to phase out Europe's reliance on Russian fossil fuels.

On the other hand, the energy crisis caused by the Russian aggression against Ukraine made some European countries resume the use of coal and fossil fuels for energy production. Unfortunately, such actions slow down decarbonization and block the measures undertaken to increase the share of RES. Because of the energy crisis, the consumption of coal in the European Union increased by another 7% in 2022, which should be added to the 14% increase in 2021 [77]. The quoted study revealed directions in the development of the energy market. One, based on RES, leads to the development of a zero-emission economy. The other one, evoked by the energy crisis, relies on fossil fuels. The two directions are mutually contradictory, and both have specific effects; the former reduces the consumption of fossil fuels, reducing negative impacts on the environment and climate change; the latter increases the emissions of GHGs and contributes to global warming. Birol [78] wrote: "We do not have to choose between responding to today's energy crisis and tackling the climate crisis. Not only can we do both, we must do both."

A significant support area consists of amendments in the law pertaining to procedures on the execution of investments into the production of energy from RES. It is worth emphasizing that the Council (EU) employs legal means to launch measures that aim to accelerate the legal procedures involved in obtaining the necessary permits to start investments in renewable energy sources [79] (Table 1). Reducing the barriers to the development of RES energy production is a direction which should remain in the legal framework in the near future, not just as a temporary solution but as a permanent one.

Table 1. Most important legal documents of the European Union.

Period	Directive	Source
1998–2009	96/92/EC, Directive 96/92/EC Of The European Parliament And Of The Council of 19 December 1996 concerning common rules for the internal market in electricity. 1997.	[51]
	98/30/EC, Directive 98/30/EC of the European Parliament and of the Council of 22 June 1998 concerning common rules for the internal market in natural gas. 1998.	[52]
	2009/28/EC, Directive 2009/28/EC Of The European Parliament And Of The Council of 23 April 2009 on the promotion of the use of energy from renewable sources and amending and subsequently repealing Directives 2001/77/EC and 2003/30/EC. 2009.	[49]
2010–2018	(EU)2018/2001, Directive (EU) 2018/2001 Of The European Parliament And Of The Council of 11 December 2018 on the promotion of the use of energy from renewable sources 2018.	[50]
2018–2022	(EU)2019/944, Directive (EU) 2019/944 of the European Parliament and of the Council of 5 June 2019 on common rules for the internal market for electricity and amending Directive 2012/27/EU. 2019.	[59]
	COM/2019/640, Communication From The Commission To The European Parliament, The European Council, The Council, The European Economic And Social Committee And The Committee Of The Regions The European Green Deal. 2019.	[61]
	COM(2021)550, Communication From The Commission To The European Parliament, The Council, The European Economic And Social Committee And The Committee Of The Regions 'Fit for 55': delivering the EU's 2030 Climate Target on the way to climate neutrality. 2021.	[62]
	COM/2022/230, Communication From The Commission To The European Parliament, The European Council, The Council, The European Economic And Social Committee And The Committee Of The Regions REPowerEU Plan. 2022.	[63]
After 2022	COM(2022)591, Proposal for a Council Regulation laying down a framework to accelerate the deployment of renewable energy. 2022.	[79]

4.1.5. What's Next?

Using RES has now become more important than ever before. This conclusion is drawn in the report on the implementation of a bioeconomy issued in 2022 [80].

The debate on external costs is also taking place at the political level. Determining an appropriate level of CO_2 tax is difficult due to political implications, but even more so because of scientific, economic and ethical considerations. A review of the literature in the European context completed by Bachmann and Till M [81] enabled the authors to identify two main approaches based on either marginal damage costs (MDCs) or marginal abatement costs (MACs). The above authors concluded that the use of the marginal damage costs method is either limited in terms of the impacts taken into account (and the ones which are taken into account are based on dated cause-and-effect relationships) or relies on impact functions based on gross domestic product (GDP) that either ignore or arbitrarily include impacts on other goods or services non-marketed, for example due to catastrophic events. In turn, the marginal abatement costs method corresponds to politically consistent costs of attaining politically set aims, targets, if existing, with no immediate links to the impacts avoided. Depending on the methodological choices made, MDCs and MACs could yield estimates different by two orders of magnitude, i.e., from less than 10 to far above 100 (EUR or USD) per 1 ton of CO_2).

The development of energy generation from biomass has encountered several barriers, such as a lack of local biomass markets, an absence of a system of subsidies to energy crop plantations, a lack of clear restrictions on the co-combustion of biomass in high-capacity coal boilers, the unpredictability of the system of support to electricity from renewable sources [82].

As documented above, support was mainly addressed to producers of energy from renewable sources. In the earlier time periods, different degrees of effectiveness of the employed support instruments was indicated, suggesting that the best effects were achieved when all instruments for the support of biomass-based energy production were applied in combination [4]. On the other hand, biomass producers have not been offered any effective support, which explains the limited supply of biomass. Biomass producers could only take advantage, to a limited degree, of subsidies to short rotation coppices (SRCs) [83]. Additionally, the production of woody biomass was based on existing forests rather than on dedicated plantations. Thus, it would be helpful if the common agricultural policy instruments could be used more extensively in order to support biomass producers, especially as such instruments were created and used in the past.

For the execution of the Community's policy related to renewable energy production, especially from biomass, it is significant to raise the production of biomass itself, so that primary biomass would not have to be used. The term 'primary forest biomass' is applied to the wood harvested directly from forests and used by the energy industry to generate 'green energy'. Polish data can be given as an example: "In years 2005–2020, there was a dynamic development of the bioenergy sector in Poland. The total capacity of installations using biomass increased sevenfold (697%), from less than 190 MW to 1512 MW. The amount of woody biomass used in bioenergy increased during that time period by almost 140-fold (13 852%) from 35,000 m^3 to 4.9 million m^3 annually." [82]. In 2020, 7.5 million m^3 of wood was harvested for energy generation, which corresponded to 18% of the total quantity of wood harvested in Polish forests. The use of forest biomass is a significant element that allows many EU countries to achieve the required percentage of energy from renewable sources [84]. Increasing the amounts of harvested forest biomass is dependent on the fact that the Directive on the promotion of the use of energy from renewable sources (Directive RED) considers it as a renewable energy source (zero-emission fuel eligible for financial support from public funds dedicated to RES).

Unfortunately, aside from subsidies to SRCs, which are small, there are no system-wide methods to support woody biomass producers. Meanwhile, problems connected with the use of primary biomass and biodiversity preservation are highlighted. In this context, the need to distinguish between different types of products from the forest economy is emphasized, together with the efforts to save primary biomass [84]. To this end, certification of the sustainable acquisition of biomass is playing an increasingly important role (FMU level) [84]. This will help to satisfy the EU Forest Strategy [85], and the EU second strategy on biological diversity [84,86].

The system of support to the production of renewable energy from biomass was based on guarantees of origin (GOs), auctions and preferences/discounts. It was assumed to be a market-driven mechanism, favoring, among other things, the optimal development of the RES sector. However, due to the high unpredictability of the size of the market of guarantees of origin and, consequently, of prices of property rights in a given time period, this system deepened the imbalance in the RES energy market. It led to an oversupply of guarantees of origin for RES-derived energy, a gradual decrease in their price and, eventually, to the limiting of this form of support. The second form of support to the production of RES-derived energy, namely the system of auctions, also proved to be insufficient. This was confirmed by the lack of auction results for technologies using biomass fuels due to the insufficient supply of electrical power from biomass offered by producers. An example can be found in the report called Evaluation of the functioning of the Support Programme in the form of an auction support system for producers of energy from renewable sources from 1 July 2016 to 31 December 2020, approved by the decision of the European Commission of 13 December 2017 SA.43697 (2015/N)—Poland—the auction system of support to renewable energy sources and energy-intensive consumers [87].

The study of Mandley et al. [88] suggests that the demand for energy from biomass in Europe will rise in the next 30 years and will play a significant role in the framework of the low-cost transformation of energy systems, thereby facilitating the achievement of climate-related targets. Biomass residues and lignocellulose plants will be important sources of local energy, which will help to ensure that the European decarbonization strategy is attainable.

An important aspect on the path to the decarbonization of the economy, and especially the energy sector, is the improvement of energy efficiency. A study by Khan et al. [89] confirmed that in the long term, improved energy efficiency and an increased share of renewable energy sources in the production of electric power decreased carbon dioxide emissions. Moreover, it has been found that energy efficiency and the inclusion of financial aspects related to the natural environment inhibit CO_2 emissions. Furthermore, the results of that research were significant when taking into account different, alternative techniques of cost estimation. The cited authors concluded that total greenhouse gas emissions can be considered as an alternative measure of environmental well-being [89].

Some stimulating influences on the profitability of energy production from renewable sources may be affected by the launching of the CBAM mechanism (carbon border adjustment mechanism), that is the mechanism of adjusting prices on borders taking into consideration emissions of CO_2. This mechanism will also cover electricity. CBAM is expected to avoid—in full compliance with the principles of international trade—such situations where the EU's efforts to reduce GHG emissions are offset by an increase in such emissions outside the Community's borders due to the translocation of production to countries which do not belong to the EU (where policies to prevent climate change are less ambitious than the EU) or due to higher imports or high-emission products [90]. The implementation of this solution can affect, in various ways, the functioning of the economy, including renewable energy production, for example, where a large proportion of photovoltaic panels comes from China. In the first years, this approach led to an increase in the investment costs in renewable energy or to the verification of the sources of its origin, giving preference to local biomass. Predictions concerning future electric power generation imply that wind turbines and photovoltaics will make an important contribution to energy transformation [91].

Social awareness has also changed, and so has the sense of the phrase 'renewable energy community', which in the past used to relate only to bottom-up initiatives supported by the active part of society, and nowadays is also understood literally, as energy-self-sufficient communities using renewable energy. This change indicates immense ideological progress, followed by technological advancement, with both leading to a socially acceptable energy model [13]. Social awareness changes under the influence of many factors. One group of factors includes conditions associated with the aforementioned social awareness supported by technological progress. Technological progress leads to an improved availability and economic viability of new solutions. Another group of factors are cases of environmental damage, such as climate change or air pollution. The combination of these two sources of motivation, supported with specific values derived from LCA and ELCC analyses, gives hope for an even more rapidly increasing share of biomass-based renewable energy in the energy generation structure.

4.2. External Environmental Costs—Internalization

There are articles in the literature which present analyses of external costs in the production of energy from RES, but they deal with energy generation technologies [92–101]. In the literature pertaining to the costs of production in agriculture, there are also some articles that include an analysis of externalities. A systematic review of LCC inclusive of external costs in the agricultural and food sector was completed by Degieter, et al. [97]. The data on the methodology and results of life cycle analyses of agri-food products were derived from 92 articles and covered a wide range of products, of which 64% represented agricultural crop plantations. The authors noted a growing interest in the use of LCC in research. At present, there are different definitions and boundaries for LCC, which means that the results cannot be easily compared. The number of studies which included external costs in a life-cycle assessment was rather limited, as only 13 out of 92 papers took externalities into account, and 8 out of 59 considered the external costs of agricultural crop cultivation. The findings achieved by the researchers indicated that LCC was often used to compare different production scenarios (e.g., conventional versus organic ones), innovative production methods with traditional ones, bioenergy with fossil fuels, or dealt with the valuation of byproducts.

Biomass can play a leading role in building energy security, particularly in rural areas. The implementation of the legal framework supporting bioenergy creates many economic, environmental and ecological benefits, including improved access to energy, new jobs and a cleaner environment [98]. An analysis of externalities conducted for agriculture in China proved that the saved production costs and environmental benefits of organic agriculture, which were determined quantitatively in the study, largely offset the economic losses due to a lower plant production output. This suggests that payments for the environmental benefits delivered by organic agriculture should be included in public policies [99].

Further evidence in favor of the inclusion of externalities in economic analysis was given by Canaj, Morrone [100]. This study included a synergistic evaluation of impacts on the environment and an economic assessment of precision irrigation in greenhouse zucchini production from a cradle-to-farm perspective. Potential environmental indicators were quantified using a life-cycle assessment (LCA) with the ReCiPe 2016 method. The economic analysis employed the life-cycle costing (LCC) approach, which took into account both costs of private products and the so-called ‘hidden’ or ‘external’ environmental costs through the monetization of the LCA results.

Another example of an analysis of external costs is found in another paper [101], which demonstrated the possibility of the internalization of externalities in agricultural production using a case study of the assessment of the impact and external costs generated by this impact from nitrate pollution caused by agricultural activity. In some circumstances, a high content of nitrates in potable water can cause health problems rather rapidly. In the analyzed case, it was determined that nearly half of the price of potable water is composed of externalities which should be internalized in agricultural production.

The environmental life-cycle costing method alone, part of which is the determination of externalities in the sphere of agricultural production, has not been used very often in economic assessments, and whenever it was, it did not take into account all costs at all stages of LCC [102].

Morel, Traverso [103] drew attention to several important questions: the calculation of externalities is a bridge between economic decisions and environmental and social evaluations, where it can provide both types of results in the same unit and is significant for the support of three decision-making levels, such as the technical solution, portfolio of products and the company's strategy. It can also help to engage the highest level of management, allowing them to adjust to the assessment of the importance of options and the stakeholders' expectations. Nonetheless, there are still many challenges connected with the correct applicability of the methodology of monetization and the approval of a company. For implementation, it is important to collect raw information throughout the whole supply chain and from consumers. The panel's recommendations were to adjust the efforts to the assumed goal of research. However, the iterative approach was strongly advocated for, suggesting that first a simplified evaluation should be conducted, and then more intricate methods should be applied if needed. The company's acceptance should rely on communicating financial results because monetization can be employed in companies at different levels. There is still one more challenge concerning the possibility of making decisions and monitoring their outcomes: how to integrate costs and revenues which are not paid or not perceived as direct benefits. Should the effectiveness of external costs be the key indicator and who would see it as such? What benefits can be gained and what positive influence on co-creators can be expected? Recapitulating, regardless of these questions, the panel highlighted what other studies needed to be carried out, and agreed that an evaluation of environmental and social costs has already achieved a high decision-making support capacity.

LCC can be seen as a valuable instrument in the evaluation of sustainable development, although the normalization of this method would enable a better comparability of the results obtained by different authors, a fact that was underlined by Degieter et al. [97]. Internalization of externalities is in part an answer to the felt need to fortify the technical and economic feasibility of integrated bioenergy systems.

4.2.1. Environmental Externalities in Soil Biomass Production—A Meta-Analysis

The changeability of economic conditions of multiannual plant production relative to geographical circumstances has been confirmed by Olba-Zięty et al. [104]. The average costs of the production of perennial crops were 74.63 EUR Mg^{-1} d.m. (i.e., 3.46 EUR GJ^{-1}). The costs of the production of willow and poplar were similar, and equaled 60.09 and 69.70 EUR Mg^{-1} d.m., respectively, while those of miscanthus were higher, at 95.09 EUR Mg^{-1} d.m. Considering the calorific value, the costs of producing willow, poplar and miscanthus were similar, at 3.36, 3.70 and 3.55 EUR GJ^{-1}, respectively, while those of Arundo donax reached approximately EUR 3.88 GJ^{-1} [105]. However, these studies showed only direct production costs, while the total production costs can only be assessed properly by including externalities in LCC, alongside the environmental costs involved in the production of bioenergy, also for energy purposes.

A statistically significant meta-analysis of the external costs of the production of energy biomass based on data from the literature published in the recent years enabled the determination of the average cost at 20.35 EUR Mg^{-1} d.m. and the 95% confidence interval of the mean as 13.86–26.85 EUR Mg^{-1} d.m (Table 2). The result of the meta-analysis was stable as it took 149 studies to induce the non-significance of the determined outcome. The meta-analysis proved the heterogeneity of the studies (I2—85%), which suggests that further studies in this scope are needed to confirm the value of externalities connected with the production of biomass for energy purposes.

Table 2. Results of the meta-analysis of externalities in biomass production for energy purposes.

External Cost (2021)	Value	Unit
Mean	20.35	EUR Mg−1 d.m.
Lower limit of the 95% confidence interval	13.86	EUR Mg−1 d.m.
Upper limit of the 95% confidence interval	26.85	EUR Mg−1 d.m.
p (effect)	0.014	-
I2	85.7	%
Fail-safe N	149	-

A complex and synthetic analysis of the range and dimension of externalities related to supplies of electricity, energy efficiency and transport as well as the research methods and techniques applied to the appraisal of externalities in monetary units were the subject of the research reported by Sovacool, Kim [106]. These authors concluded that the average external cost of the production of electric power from biomass was 7.64 ¢ kWh^{-1} (adjusted to USD 2018) and 7.95 ¢ kWh^{-1} (adjusted to EUR 2021). When comparing these values to the ones obtained in this study, using the converted per mean calorific value of 17.8 GJ Mg^{-1} d.m. and considering the euro exchange rate of 2021, the authors arrived at a value of 10.06 ¢ kWh^{-1} (confidence interval of 6.85–13.28 ¢ kWh^{-1}). The most important political question posed by the authors was whether we accept the global energy markets, which manipulate with the occurrence of externalities for their benefits, or whether we expect political and legal measures that will allow the internalization of these costs.

The authors of this article, in the same way as Jorli et al. [18], are aware of the occurrence of some uncertainties accompanying any calculation of externalities. However, it is better to have an estimate of externalities rather than to completely neglect them. The research should be continued in order to collect global and local data, especially in terms of estimates of costs of health damage. The results will enable us to diminish the uncertainty of any estimate of external costs.

4.2.2. Analysis of Key Words

Our analysis of key words in the reviewed literature enabled us to identify 407 key words, of which life-cycle assessment and life-cycle costing appeared several times, sometimes in slightly changed forms (e.g., full name, abbreviation, etc.) (Figure 2), which—following some correction—allowed us to identify 81 key words. The most frequent key words were life-cycle assessment and life-cycle costing. It is worth emphasizing that the frequency of their occurrence implicated the key role of these two methods in analyses of sustainability, in which an analysis of externalities was an important element.

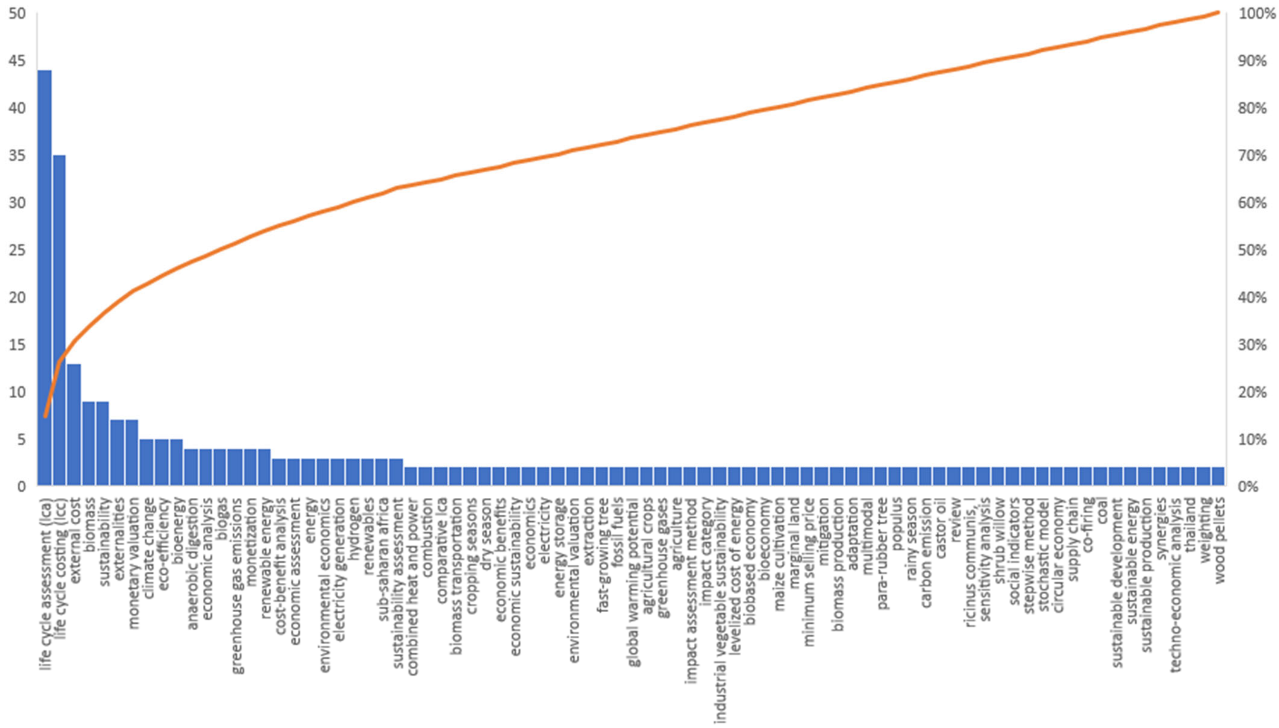

Figure 2. Pareto chart of keywords frequency.

4.2.3. Analysis of Co-Occurrence

Our analysis of the co-occurrence agglomerations revealed that the most common key word in the biggest cluster (marked with the red color) was 'life cycle assessment', followed by 'sustainability' (Figure 3). This finding was convergent with the results of our comparative analysis, which pointed to the LCA method as being the most popular one for the identification of externalities. Although the main subject in this paper is the external costs of biomass production for energy purposes, and the terms associated with this research aim were searched for among key words, their choice most often emerged from considerations preceded by a life-cycle assessment where the external effects which could undergo monetization were identified. Thus, the frequent co-occurrence of such terms as 'external costs', 'externalities', 'life cycle costing', or 'economic analysis' in the context of ensuring eco-efficiency verifies the previous conclusions drawn from the literature perusal. The other five clusters were characterized by a less frequent co-occurrence of words than in the first cluster. Noteworthy is a considerably high frequency of the occurrence of 'life cycle costing' or 'LCC', which made up quite a large share among the terms in three of the five clusters (marked with the yellow, green, and blue colors), and 'external costs' and 'monetary value', which represented a large share in the other two clusters (marked with the blue and purple colors), but these terms were not used in this analysis. The analysis of the co-occurrence of key words justifies the conclusion that research papers dealing with externalities in biomass production included such issues as climate change or GHG emissions. This is consistent with other comparative analyses of references, e.g., Bachmann, Till [81] who focused on analyses of the environmental costs of greenhouse gas emissions.

The analysis of agglomerations led to the identification of the co-occurring words connected with the subject, that is biomass, bioenergy, energy, renewable energies, but to a lesser extent. However, their occurrence proved that the selection of the literature references concerning biomass production for energy purposes was correct, while the detailed analysis of the literature let us address another issue related to biomass production for energy purposes in the context of external costs, that is the competition for agricultural land. The production of biomass for energy purposes should take place on the land that does not compete with the production of food or fodder, although it does not undermine the idea that the latter should constitute an important component of agricultural production as well [83].

A commonly advocated solution to the problem of competition for land between food and feed production versus the production of energy crops is to grow the latter on marginal lands. Marginal land is defined as infertile agricultural soils, chemically polluted soils or mechanically transformed soils lacking the fertile horizon, or else soils with unfavorable natural and land-relief conditions, where plant production for food or fodder is unprofitable [107]. The results indicate that landowners who possess marginal lands in their farms grow energy crops more often and need less incentive to accept the price than landowners who do not have marginal lands. It was also noted that farmers not familiar with these new crops are more often worried about the profitability of energy crops and demonstrate less willingness to set up such plantations.

Among the key words indirectly connected with the subject of this research, the words 'anaerobic digestion' and 'biogas' occurred quite often, thus indicating an interest shared by some of the authors in the further stages of the conversion of biomass to energy. During our comparative analysis, we also came across articles where the subject of an analysis was the production of biomass as an intermediate step in the production of pellets [108–110].

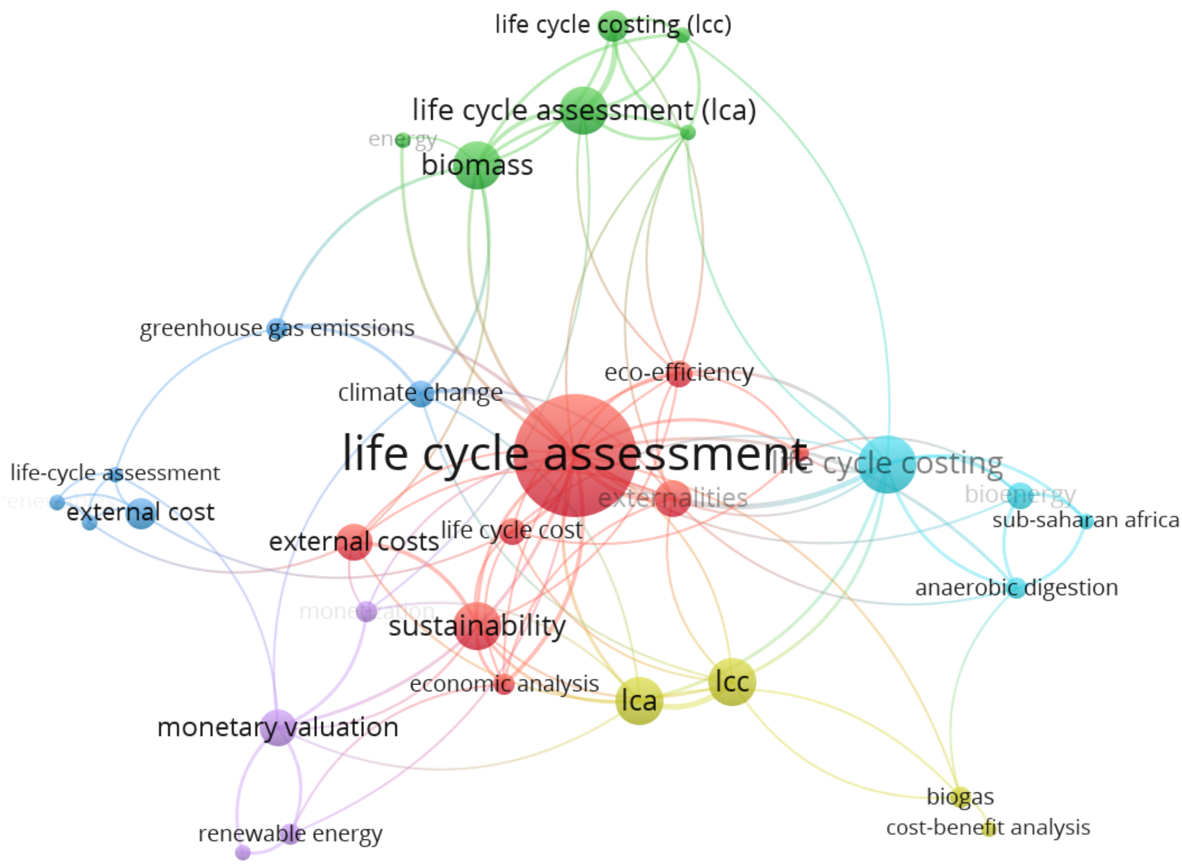

Figure 3. Network visualization of papers selected for analysis.

Our analysis of the temporal variability of the co-occurrence of key words gave an insight into how the interest in this subject has developed in recent years. Earlier, externalities were identified in relation to biogas and eco-efficiency. Most papers covering the life-cycle assessment and life-cycle costing concepts were published in 2020, and subsequent articles referred mainly to monetary valuation, renewable energies and LCA The most recent publications highlight life-cycle costing and sustainability, which is consistent with the results of the comparative analysis, which emphasized the internalization of external costs as an element of the evaluation of sustainability (Figure 4). Degieter et.al [97] drew attention to the growing challenges that the global food system faces in the social, economic and environmental dimensions, as well as the obligation to satisfy the United Nations Sustainable Development Goals (SDGs) by the year 2030, where agri-food systems must become more and more sustainable. Tools of life-cycle analysis such as life-cycle assessment (LCA) and life-cycle costing (LCC), which serve to evaluate the environmental and economic efficiency, respectively, play an important role in research on sustainable development.

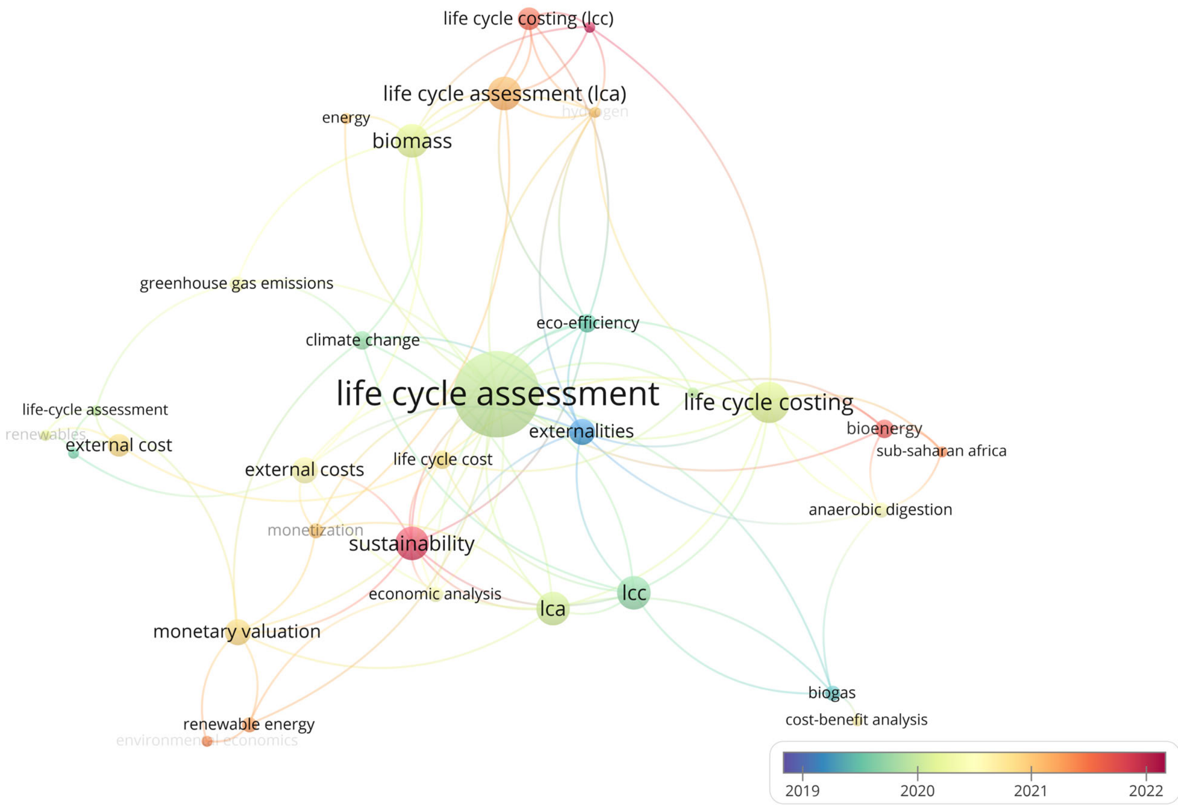

Figure 4. Overlay visualization of papers selected for analysis.

5. Conclusions

EU policy and the laws passed under its influence over the past 15 years have supported and stimulated the development of renewable energy sources. The Russian invasion of Ukraine has changed the European energy market tremendously and forced countries to review previous assumptions and to propose new solutions, which will enable them to pursue such goals as reducing greenhouse gas emissions in Europe by 55% by the year 2030, or reaching climate neutrality by the year 2050, as well as making Europe independent from Russian fossil fuels, for example by taking steps to increase the production of renewable energy. Against this backdrop, the production of solid biomass for energy purposes gains importance, especially as it can be grown locally and can contribute substantially to a country's energy security. A question then arises whether the external costs of the production of energy from sources other than fossil fuels should also be analyzed. The positive answer seems obvious—unfortunately, the literature provides very few examples of studies which take into account externalities of biomass production. Such studies are extremely important as they show the actual costs of production of renewable energy, the profitability of their production and their competitiveness relative to fossil fuels, especially nowadays, when the impact of using fossil fuels on human health, the natural environment and climate has been confirmed.

Analysis of external environmental costs has featured in political, legal, economic, agricultural and energy-related debates. Externalities are most often included in assessments of the production of electricity from both renewable and non-renewable sources. There is a growing number of papers analyzing the economic aspects of biomass production which employ an analysis of costs in a life cycle, but very few studies also include externalities. The results and interpretation from the perspective of previous studies and the working hypotheses should be presented. The findings and their implications should be discussed in the broadest context possible. Future research directions may also be highlighted.

There are some important limitations mentioned in the literature which the authors of this paper would like to question, namely that the calculation of external costs is burdened with uncertainty. We believe this is an argument for why they should be analyzed. Neglecting external costs leads to erroneous calculations, distorts markets and sanctions the negative impact on the climate and environment.

Environmental analysis of costs in a life cycle integrated with a normalized analysis of life cycle is a valuable tool for the evaluation of sustainability, but its value can be enhanced if the method itself has been normalized. The authors are aware of the presence of external social costs whose occurrence and analysis are an equally important aspect of any assessment of sustainability, but which were not the subject of this article.

Solid biomass is not the source of renewable energy on the path to a zero-emission bioeconomy. The leading contribution in the generation of electric power is and will be made by both photovoltaics and wind turbines, but it is not the aim of this article to discuss these sources.

The article presents the role and importance of the internalization of environmental externalities of biomass production for energy purposes. Likewise, the social costs and benefits, however important, were not the subject of this paper.

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Abbreviations

¢	Euro Cents
EUR	Euro
CBAM	Carbon Border Adjustment Mechanism
CLCC	Conventional Life-Cycle Costing
CO_2	Carbon Dioxide
d.m.	Dry Matter
ELCC	Environmental Life-Cycle Costing
EU	European Union
FMU	Forest Management
GDP	Gross Domestic Product
GHG	Greenhouses Gas Emissions

GJ	Giga Joule
GSP	Global Sustainability Panel
GWP	Global Warming Potential
kWh	kilo Watt hours
LCA	Life-Cycle Assessment
LCA	Life-Cycle Assessment
LCC	Life-Cycle Costing
LULUCF	Land Use, Land Use Change and Forestry
MACs	Marginal Abatement Costs
MDCs	Marginal Damage Costs
Mg	Megagram
NO_2	Nitrogen Dioxide
PM	Particulate Matter
$PM_{2.5}$	Particles of <2.5 µm in Diameter
RED	Renewable Energy Directive
RES	Renewable Energy Sources
SDGs	Sustainable Development Goals
SLCA	Social Life Cycle Assessment
SRCs	Short Rotation Coppices
UN	United Nations
USD	United States Dollars

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