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Possible Futures towards a Wood-Based Bioeconomy: A Scenario Analysis for Germany

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Abstract: Driven by the growing awareness of the finite nature of fossil raw materials and the need for sustainable pathways of industrial production, the bio-based economy is expected to expand worldwide. Policy strategies such as the European Union Bioeconomy Strategy and national bioeconomy strategies foster this process. Besides the advantages promised by a transition towards a sustainable bioeconomy, these processes have to cope with significant uncertainties as many influencing factors play a role, such as climate change, technological and economic development, sustainability risks, dynamic consumption patterns and policy and governance issues. Based on a literature review and an expert survey, we identify influence factors for the future development of a wood-based bioeconomy in Germany. Four scenarios are generated based on different assumptions about the development of relevant influence factors. We discuss what developments in politics, industry and society have a central impact on shaping alternative futures. As such, the paper provides a knowledge base and orientation for decision makers and practitioners, and contributes to the scientific discussion on how the bioeconomy could develop. We conclude that the wood-based bioeconomy has a certain potential to develop further, if adequate political framework conditions are implemented and meet voter support, if consumers exhibit an enhanced willingness to pay for bio-based products, and if among companies, a chance-oriented advocacy coalition of bioeconomy supporters dominates over proponents of fossil pathways.

Keywords: scenario development; bioeconomy; Germany; uncertainty; renewable resources; wood

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1. Introduction: The Wood-Based Bioeconomy—Aims, Perspectives and Uncertainties

Driven by the growing awareness of the finite nature of fossil raw materials and their climate change impacts as well as the need for more sustainable methods of industrial production and consumption patterns, the bio-based economy is expected to expand in the future. The bioeconomy sector is seen as a warrantor for a green economy: "[. . .] the use of biomass offers solutions to many of the problems of the fossil-input-based economy: it ensures both energy diversity and security and is environmentally friendly, owing to carbon sequestration and the resulting climate change mitigation" [1] (p. 454). As a result, expanding the bioeconomy has been identified as a strategic aim by the EU [2] and member states, such as Germany [3,4]. Also internationally, the transition to a bioeconomy garners political support [5].

Meanwhile, the definition of the bioeconomy concept is still under discussion [6]. The European Commission (EC) [2] (p. 3) defines "Bioeconomy" as encompassing "the production of renewable biological resources and the conversion of these resources and waste streams into value added products, such as food, feed, bio-based products and bioenergy. Its sectors and industries have strong innovation potential due to their use of science, enabling and industrial technologies, along with local and tacit knowledge". This means that the bioeconomy intends to substitute fossil resources and to close material cycles in industrial processes by using renewable resources such as plant materials like wood and agricultural crops, animal by-products and waste.

The wood-based bioeconomy describes an important sub-sector of the overall bioeconomy. Wood-based bioeconomy can be defined as a bio-based circular economy that uses lignin-containing and, therefore, hard parts of stem, branches and twigs of plants such as trees and scrubs. The biggest part of utilised wood originates from forests such as round timber, pulpwood and forest residues, while smaller parts of utilised wood derive from short rotation coppice and landscape residues. Furthermore, by-products and waste of wood processing and also recycled wood are utilised for material and energetic use. The wood-based bioeconomy has a high relevance for both material and energetic uses because there is no direct competition with food production.

While the bioeconomy receives increasing attention in the political sphere, its advantages, risks and further development remain uncertain, as many influence factors such as resource availability and costs, climate change, technological as well as economic development play a crucial role [7]. The development of supportive policies at different levels will also impact on the bioeconomy [5,8]. In competing with fossil fuel-based products and production processes, bio-based substitutes are encumbered by market failures, such as the limited internalisation of environmental costs of fossil fuel use [9,10]. Moreover, fossil-based production pathways can benefit from economies of scale and scope, past learning effects and a co-evolution of technologies and institutions, resulting in a lock-in into fossil fuel-based production structures and demand patterns [11,12]. At the same time, investments in innovative bioeconomy pathways are associated with knowledge and learning spillovers, which, as positive externalities, result in lower levels of innovative activities than socially optimal [13,14]. A well-coordinated policy mix is required to ensure the effective functioning of the bioeconomy innovation system which can support a path transition towards a sustainable circular flow economy based on renewable resources, by encouraging not only investments in innovation but also the diffusion of innovative technologies and products and their progress towards commercial maturity [15]. However, how political influence factors might unfold is strongly connected to social acceptance of bioeconomy concepts [5]. Meanwhile, uncertainties do not only apply to influence factors, but also to the impacts of the bioeconomy [5,8,16]. GHG mitigation potential and other environmental and socioeconomic impacts of biomass uses depend on a large range of allocation decisions for heterogeneous material and energetic pathways. To ensure that the transition to a bioeconomy is a sustainable one, an adequate governance framework is required.

Scenarios represent a helpful tool for analysing alternate development pathways of an uncertain future [17,18]. Scenarios are defined as "plausible stories about how the future might unfold, constructed using qualitative and/or quantitative models and information on current and past conditions" [19] (p. 1). Ideally, scenarios can support the establishment of policy frameworks and decision making of policy makers who want to take into account a long-term perspective [20–23]. Companies also play a key role in the development of the bioeconomy and scenarios can contribute to an early identification of success potential, the timely development of which companies rely on to remain competitive [24] (p. 113).

Qualitative scenario approaches are particularly suitable when we have only a limited understanding of the causal relationships within a system that prevents quantification of these relationships in models [25]. Qualitative approaches are also particularly suitable for decision support focused on developing or testing specific policies [19]. For example, the UK Government Office for Science contracts foresight projects to examine important public policy issues, e.g., ageing population of development of cities [26]. The Royal Dutch Shell group uses qualitative scenarios to explore the robustness of long-term business strategies across a range of plausible future business environments [27]. By providing structure to an uncertain decision making context, qualitative scenarios do not only provide decision support for businesses but have also proven to be relevant to analyse new emerging policy fields as described e.g., by Purkus and Barth [28] for the case of geothermal energy. With the bioeconomy, we are dealing with a new policy field where uncertainties are high, but decisions already have to be made; therefore, we chose a qualitative scenario approach to explore alternative futures for the wood-based bioeconomy, and identify what influence factors have a key role in shaping its future course. Reasons for focusing on wood are that it is not part of the food *vs.* fuel debate [29] and has an increasing innovation potential because lignocellulosic raw materials can be used for material but also chemical processes and products [30,31].

We use the development of the German bioeconomy up to 2050 as a case study. In line with the EU's vision for a sustainable bioeconomy [2], Germany has adopted several national strategies supporting the transition [4,32] (see Section 3.1). More specifically, the wood-based bioeconomy is supported as part of these strategies, as well as through the establishment of a German "Excellence Cluster BioEconomy" [33] mainly referring to woody biomass and supporting knowledge exchange between industry and science in order to develop sustainable bioeconomy processes and products. Using the German case study, we identify the main influence factors that impact the development of the wood-based bioeconomy. Scenarios illustrate how they interact to either promote or hinder the path transition to a sustainable bio-based economy, and provide information on the role of key actors such as politics, the industry, consumers and voters. Furthermore, we are able to identify influence factors which can act as levers for steering the development of the bioeconomy. After explaining our methodology (Section 2), we present our results on key influence factors and develop scenarios (Section 3). Then, we discuss implications for politics, companies and the society (Section 4), before drawing conclusions (Section 5).

2. Scenario Analysis: Methodology and Inputs

Scenario analysis, as part of the methodological toolkit of science–policy interfaces [34], has grown significantly over the last two decades. Likewise, the number of approaches to develop scenarios has increased (for an overview see e.g., March *et al.* [17] or Rounsevell and Metzger [25]). For our qualitative scenario development, the approach by Gausemeier *et al.* [24] is applied, which is well suited for structuring complex systems of influence factors. This approach requires the following five stages: preparation (i), scenario field analysis (ii), scenario prognosis (iii), scenario development (iv), and scenario transfer (v). The integration of expert knowledge in the scenario analysis (such as defining influence factors, identifying their relevance and interdependencies, setting up the storylines and scenario interpretations) ensures that these scenarios are plausible, credible and relevant for potential users, as will be explained in more detail in this section.

The preparation stage encompasses the description of the status quo of the study object, in our case the wood-based bioeconomy in Germany, and the potential for its future development (Section 3.1). We consider this description to be of particular importance, because information on the framework conditions is crucial for the scenario prognosis in the next step [28]. Based on this analysis, key actors in the field of the wood-based bioeconomy were identified.

In a first step, 22 generally relevant influence factors were identified through a comparative literature review of existing scenarios with a focus on "wood/forest", "bioeconomy", "land-use" or "industry" (Section 3.2). For this purpose, altogether nine scenarios were analysed in detail (see Table S1), such as existing genuine bioeconomy scenarios (e.g., [23]), scenarios on the development of the chemical industry [35] or the scenario "Forest Futures 2100" [36]. The thus identified 22 generally relevant influence factors were categorised into five different segments that these factors might be attributed to, comprising society, technology, economy, ecology and politics, following the approach of Steinmüller *et al.* [36] for "Forest Futures 2100". To cover a broad range of relevant influence factors it is considered essential in the literature "to build a coherent image of the future" [17] (p. 133). Hence, factors from all socio-economic as well as environmental and technological realms have been included here. To check for potential interactions between these factors, "interaction matrices" prove to be particularly helpful [37]. Therefore, a cross-linking matrix was used in our study to evaluate and display interactions. We also identified which influence factors have a strong impact on other influence factors (active/dynamic) and which are less influential themselves but are reversely influenced by other influence factors of the system (passive factors) (see Section 3.2). This approach allows for an identification of factors which can be used as levers to influence the system's development [24,37] (see also [28]).

At this stage of the scenario development, stakeholders can be engaged to identify the interactions between different influence factors. Potential formats of stakeholder engagement are workshops, discussion rounds and interviews [18]. In our case, 18 experts from the German "Excellence Cluster BioEconomy" were involved by a recorded survey. They represent scientists from different disciplines (such as law, economics, engineering science) as well as representatives of involved industries and the cluster management, all of whom are working on enhancing the sustainability of material and energetic uses of woody biomass. Moreover, the cluster brings together all relevant sectors along the value chain like the timber and forestry industry, the chemical industry, the plastics industry and plant engineering. The experts were asked to identify only five so-called "key influence factors" each (with highest attached importance) and relate these to all the other 21 generally relevant influence factors (Sections 3.2 and 3.3). Experts were also allowed to add additional influence factors that might have been missing in the list. We visualized the results, *inter alia*, as a system grid, to understand influence factors' relative role and degree of integration in the system (Figure 3 in Section 3.2). This step was important to specify our scenarios, and for the subsequent derivation of implications for politics, companies and the civil society. To form a structure for the scenarios, basic assumptions were formulated concerning the attitudes of key actor groups considered in our scenarios, *i.e.* politics, consumers, voters and companies (Section 3.4).

Projections of key influence factors (Section 3.4) are the basis for the construction of illustrative storylines (Section 3.5). Three criteria have to be fulfilled for scenario building [38]: Consistency, stability and diversity. Consistency is ensured when the key influence factors interact smoothly and do not reveal contradictions. Stability means that if changes are made to one of the projections of an influence factor, the scenario itself does not break down. Diversity requires that scenarios and storylines should preferably present contrasting pictures of the future [37]. For all key influence factors, the most consistent, robust and diverse combinations of projections were selected intuitively, to limit the complexity of scenarios. Following the suggestion of Priess and Hauck [18], we used several rounds of iteration, *i.e.*, checking the storylines from different perspectives (e.g., economics, politics) for contradictions, to ensure internal consistency of the storylines.

In a last step, the storylines were interpreted by the research team and conclusions were derived for relevant stakeholders. The advantage of including stakeholders is to integrate expert knowledge in scenario development to ensure that these scenarios are plausible, credible and relevant for potential users. Who is regarded as a relevant stakeholder depends on the topic and the aim of the scenarios. In the case of the scenarios developed here, these are politicians and companies.

3. Scenario Analysis

The scenario analysis is structured according to the methodology presented in Section 2 and consists of five different subsections: the status quo analysis of the wood-based bioeconomy in Germany (Section 3.1), the identification of key influence factors (Section 3.2), the characterization of these key factors and the formulation of projections concerning their future development (Section 3.3), the definition of scenarios (Section 3.4) and the presentation of the storylines (Section 3.5).

3.1. Status Quo: Current State and Further Perspectives of the Wood-Based Bioeconomy in Germany

The average share of bioeconomy sectors in the German economy slightly increased over the last years: for instance, the use of bio-based plastics in the consumer goods industry grew from less than

100 tons in 2004 to 37,000 tons in 2011 [39] (p. 265). Overall, the energetic and material use of wood has doubled over the last two decades, reaching 135.4 million m^3 in 2012 [40]. While wood-based value creation is significant for the German economy [41] (p. 15), the material use of wood is dominated by conventional applications such as woodwork or paper industries, with limited growth expectations for the future [40,42]. Moreover, a large demand for wood comes from energetic applications, whose use of wood has surpassed material applications for the first time in 2010 [40]. On the other hand, the material use of wood for innovative applications such as the chemical industry is quite low with 2.2% of total wood usage in Germany [39] (p. 58). For innovative wood products, such as Wood Plastic Components (WPC), the Federal Ministry for Food and Agriculture [4] prepares measures for the development of emerging markets, such as information for consumers about excellent wood products from deciduous trees. In Germany, an area of 11 million hectares is covered with wood land; the overall forest area has grown by 1 million hectares in the last 40 years [3].

Sustainability of forest management is safeguarded by the German Federal Forest Act and the Forest Acts of the German federal states (Länder). Further efforts are made regarding more efficient and environmentally friendly timber harvesting methods [42], especially regarding the protection of soils [32]. In addition to forest wood, further resource potentials for the wood-based bioeconomy in Germany are wood shavings, bark, and forest residues [3], but also landscaping residues, scrap wood from cascade use, and wood from short rotation coppice or from certified imports [40,43].

German economic policy has committed itself to the strategic option of the bioeconomy, as laid down in several strategic papers of the Federal government such as the "National Policy Strategy on Bioeconomy" [4], the "National Research Strategy BioEconomy 2030" [32], the "Action Plan of the Federal Government on Material Usage of Renewable Resources" [42] and the "National Biomass Action Plan" [43] (Table 1). However, there is not yet a comprehensive bioeconomy policy in Germany; neither has there been great pressure to establish one from the electorate, which is quite fragmented due to diverse aims and interests of society, politics and companies [44]. Consequently, bioeconomy sectors follow different laws and regulations for their specific sector such as the chemical industry. Some general regulations, such as the German Waste Management Act, implicitly also affect the whole value chain of the bioeconomy, but so far it does not offer many incentives for the bioeconomy to grow [45]. Similarly, climate policy could set strong incentives for exploring alternatives to emission-intensive fossil fuels. So far, however, policy measures which increase the costs of fossil fuels are limited to the energy sector (prominently the EU ETS and different energy-related taxes), and lack effectiveness in initiating structural changes [46,47]. The limited internalisation of environmental costs distorts competition between renewable resources and fossil fuels, as does the existence of technological and institutional path dependencies which favour a fossil-based "throughput economy" [48,49]. Moreover, competition between energetic and material wood uses is distorted by the existence of deployment support for energetic wood uses, such as feed-in tariffs and feed-in premiums under the German Renewable Energy Sources Act [50], or a reduced Value Added Tax on firewood.

Certification is an instrument to increase demand and supply for bio-based products, because at present fossil resources are still the main input factors for industrial production [1]. Some labels and standards for bio-based products have already been developed, e.g., for the determination of biobased content in solid recovered fuels [51] or for the evaluation of the compostability of plastics [52], and several bio-based product standards are currently under development in Europe, e.g., for sustainability criteria for bio-based products [53] or life cycle assessment of bio-based products [54]. Some sectors, such as the packaging and the automobile sector, stimulate the production of bio-based products because they provide comparative advantages over fossil-based products. However, the majority of industries still use fossil resources because bio-based alternatives are either not available or too expensive.

Another lever to support the development of the bioeconomy is research [4] (p. 27). The pressure on technological development is high: "Technological developments must guarantee more efficient conversion techniques, resolve some of the biomass competition issues and decrease the cost of producing bio-based goods." [1] (p. 460). However, many sustainability concerns are raised in this respect [55]. Deficiencies in technological development and sustainability-related uncertainties can contribute to technology research staying on the laboratory and pilot scale, instead of reaching demonstration or industrial scales; the latter would be necessary to create or open up markets for bio-based products.

Besides technological development, the availability of a sustainable biomass stock is an important prerequisite for companies to invest in new technologies and shift their product portfolio towards bio-based products. Even though fossil fuels are subject to price fluctuations, in the medium term, companies can rely on resource availability, whereas for biomass several unknown factors such as effects of climate change, nature conservation consequences and cultivation decisions have to be taken into account.

Table 1. German policy strategies and programmes impacting on bioeconomy development.

No.	Strategies and Programmes	Content
1	"National Policy Strategy on Bioeconomy" (German Federal Ministry of Food and Agriculture) [4]	Main strategies concerning the material recovery of biogene resources, including wood
2	"National Research Strategy BioEconomy 2030" (German Federal Ministry for Education and Research) [32]	
3	"Action Plan on Material Usage of Renewable Raw Materials" (German Federal Ministry for Consumer Protection, Food and Agriculture) [42]	
4	"National Biomass Action Plan for Germany" (German Federal Ministry for the Environment, Nature Conservation and Reactor Safety/German Federal Ministry for Consumer Protection, Food and Agriculture) [43]	
5	"Perspectives for Germany. Our strategy for sustainable development" (German Federal Government) [56]	Overarching guidelines for a sustainable development
6	"Ideas. Innovation. Prosperity. High-Tech-Strategy 2020 for Germany" (German Federal Ministry for Education and Research) [57]	Important strategies regarding Research and Development
7	"6th Energy Research Programme of the Federal Government" (Federal Ministry of Economics and Technology) [58]	
8	"Strengthening Germany's Role in the Global Knowledge Society. Strategy of the Federal Government for the Internationalisation of Science and Research" (German Federal Ministry for Education and Research) [59]	
9	"Health Research Framework Programme of the Federal Government" (German Federal Ministry for Education and Research) [60]	Important strategies regarding health and nature protection
10	"National Strategy on Biological Diversity" (German Federal Ministry for the Environment, Nature Conservation and Reactor Safety) [61]	
11	"Forestry Strategy 2020" (German Federal Ministry for Consumer Protection, Food and Agriculture) [62]	Strategies regarding wood and forests in general
12	"Increased wood use" (German Federal Ministry for Consumer Protection, Food and Agriculture) [63]	
13	"Joint instruction on the procurement of wood products" (Federal Ministry of Transport, Building and Urban Affairs) [64]	

Source: Own composition.

On the demand side, consumers are not yet aware of the products and possibilities the bioeconomy may provide, such as the reduction of weight of materials and products [65] or the use of environmentally friendly product components such as ecological glues [66]. One of the very few case studies on acceptance of bioeconomy was conducted by Vandermeulen *et al.* [1] who found that consumer awareness of bioeconomy products is rather low; moreover, their advantages are not easily communicated as they have similar features as fossil-based products, but are higher in price. To bring the acceptance of bio-based products forward, communication has to be enhanced, which ranks among the aims of the European and German bioeconomy strategies [4] (p. 27). However, as De Besi and McCormick [67] (p. 10473) find, while at present bioeconomy strategies across Europe admit that societal awareness is crucial for a successful transition towards a bio-based economy, the key priorities of European strategies for developing the bioeconomy focus mainly on "fostering research and innovation, primarily in the field of biotechnology; promoting collaboration between industry, enterprises and research institutions; prioritising the optimized use of biomass by implementation of the cascade principle and by utilising waste residue streams; and providing funding support for the development of bio-based activities".

The diverse interests of different actor groups such as industry and consumers are also reflected in the voter market. The preferences and characteristics of voters determine, for example, if they are likely to support or object to sustainability policies that noticeably impact prices; this influences the outcome of political decision making processes. From the status quo analysis of this chapter, we can derive four relevant actor groups which are the state/politics, companies, consumers and voters.

3.2. Identification of Generally Relevant Influence Factors

As described in Section 2, the authors conducted a comparative literature review of existing scenarios [36] and divided generally relevant influence factors into the societal categories society/ consumers, economy and producers, politics, technology and environment (Table 2). The 22 generally relevant influence factors from Table 2 were then assigned to an interaction matrix (Figure 1).

Table 2. Generally relevant influence factors for the development of the wood-based bioeconomy.

Societal Categories	**Generally Relevant Influence Factors**	
Society/Consumers	1A	Public influence
	1B	Environmental awareness
	1C	Risk and innovation attitude
	1D	Willingness to pay for bio-based products
	1E	Voting behavior (supporting sustainable politics)
Economy/Producers	2A	Globalisation and global economic development (oil price/exports)
	2B	Domestic economic development
	2C	Supply and demand for wood
	2D	Willingness to invest in innovations
	2E	Focus on short term- or long term-oriented profit
	2F	Site conditions (e.g., establishment of businesses, infrastructure)
Politics	3A	Energy and climate policies
	3B	Technology, innovation and research policies
	3C	Forest, environmental and nature conservation policies
	3D	Support of the circular flow economy
	3E	Support of local value chains
	3F	Direction of economic, competition, tax, industry and agricultural policies
	3G	Regional planning and development (e.g., role of federal states and regional associations)
Technology	4A	Innovations along the value chain of wood (including products)
	4B	Innovations for the exploitation of fossil resources (non-conventional)
Environment	5A	Climate change
	5B	Biomass availability/forest structure

Source: Own composition.

Figure 1 shows for each factor the median value of the assessments undertaken by the 18 experts involved in the survey. An influence factors' systemic role can be characterized by two values—its active sum, which depicts the influence factors' impact on all other influence factors, and the passive sum, which measures how strongly an influence factor is influenced by all other influence factors in turn [37].

		1A	1B	1C	1D	1E	2A	2B	2C	2D	2E	2F	3A	3B	3C	3D	3E	3F	3G	4A	4B	5A	5B	Active sum
(1A)	Public influence	/	2	2	2	2	0	2	0	1	1	2	1	0	1	1	2	1	0	0	0	2	0	**22.0**
(1B)	Environmental awareness	2	/	1.5	1.5	1.5	1	1	1	1.5	0.5	1	1.5	1.5	1.5	1.5	1	1	0.5	1	1.5	1.5	1.5	**26.5**
(1C)	Risk and innovation attitude	1	0.5	/	0.5	1.5	0.5	1.5	0	2	1	1.5	1.5	1.5	1.5	0.5	0	1	1	1	2	0.5	0	**20.5**
(1D)	Willingness to pay for biobased products	1	1	1	/	1	1	1	2	2	0	0	1	1	1	1	1	1	0	1	0	1	1	**19.0**
(1E)	Voting behavior	1	0	0	1	/	0	1	1	0	0	0	2	1	0	0	1	1	0	0	0	0	0	**9.0**
(2A)	Globalisation and global economic development	1	1	1	1	1.5	/	2	1	2	1	1	2	2	1	1	1	1	0	1	2	1	1	**25.5**
(2B)	Domestic economic development	0	1	1	2	1	0	/	1	2	2	2	1	1	1	1	2	1	2	2	1	1	1	**26.0**
(2C)	Supply and demand for wood	0	0.5	1	1	0	1	1	/	1	1	1	1	1	2	1	1	1	1	2	0	0.5	2	**20.0**
(2D)	Willingness to invest in innovations	1	0.5	1.5	0.5	0	1.5	2	0.5	/	2	1	0.5	1	0	0.5	1	0.5	1	1.5	2	0.5	0.5	**19.5**
(2E)	Focus on short term or long term oriented profit	1	0	1	0	1	0	2	1	2	/	0	1	1	1	1	1	1	1	2	1	0	1	**19.0**
(2F)	Site conditions	1	0	0	0	1	1	2	0	1	1	/	0	1	1	1	2	2	2	1	0	0	0	**17.0**
(3A)	Energy and climate policies	1	1	1	1	1.5	1	1	1	2	1	0	/	2	1	1	1	2	1	1	2	1	1	**24.5**
(3B)	Technology, innovation and research policies	1	1	2	1	1	2	1	1	2	1	1	1	/	1	1	1	2	1	2	2	1	1	**27.0**
(3C)	Forest, environmental and nature conservation polices	1	1.5	0.5	1	1	1	1	2	1	0	1	1	0	/	1	1	0	0	2	0	0	2	**18.0**
(3D)	Support of the circular flow economy	0	1.5	1.5	1.5	1	1	1.5	2	1.5	1.5	1.5	0.5	1.5	1.5	/	1.5	1.5	1.5	2	1	1.5	1.5	**28.5**
(3E)	Support of local value chains	2	1	0	1	2	1	2	1	1	2	2	1	1	1	1	/	0	2	1	1	0	2	**25.0**
(3F)	Direction of economic, competition, tax, industry and agricultural policies	1.5	1.5	0.5	0.5	1.5	0.5	1.5	2	2	0.5	2	1.5	2	2	1.5	1.5	/	1.5	1	1	1.5	1	**28.5**
(3G)	Regional planning and development	1	0	0	0	0	0	1	1	0	0	1	0	0	1	1	1	0	/	1	0	0	1	**9.0**
(4A)	Innovations along the value chain of wood	0.5	1	1	1	0	0	1.5	2	2	1	0.5	0	1	1	0.5	1	0.5	0.5	/	1	0.5	1	**17.5**
(4B)	Innovations for the exploitation of fossil resources	0	1	1	0	1	2	0	0	2	2	1	1	1	0	0	0	1	0	0	/	2	0	**15.0**
(5A)	Climate change	2	2	2	1	2	2	2	2	2	1	1	2	2	2	1	1	2	2	1	2	/	2	**36.0**
(5B)	Biomass availability/ forest structure	0	1	1	1	1	0	1	2	1	1	1	1	1	2	1.5	1	1	1	2	0.5	1	/	**22.0**
	Passive sum	**19.0**	**19.0**	**20.5**	**18.5**	**22.5**	**16.5**	**29.0**	**23.5**	**31.0**	**20.5**	**21.5**	**21.5**	**23.5**	**23.5**	**19.0**	**23.0**	**21.5**	**19.0**	**25.5**	**20.0**	**16.5**	**20.5**	**475**

Figure 1. Interaction matrix of influencing factors. Source: Own composition. Subsystems of the environment relevant to the development of the bioeconomy: society/consumers (1), economy and producers (2), politics (3), technology (4), environment (5). "0" means no influence, "1" a weak influence, "2" a strong influence between two factors. Number of influence factors: 22. Mean active sum = mean passive sum = 22.

Based on experts' responses (Section 3.2), the following six influence factors were identified as "key influence factors" with highest importance for the wood-based bioeconomy development: "biomass availability/forest structure", "globalisation and global economic development", "energy and climate policies", "supply and demand for wood", "willingness to pay for bio-based products" and "innovations along the value chain of wood" (see Figure 2). A factor has been selected as "key" for the study if it was named by experts more than twice as frequent as the overall mean value. This applies for the above mentioned six factors.

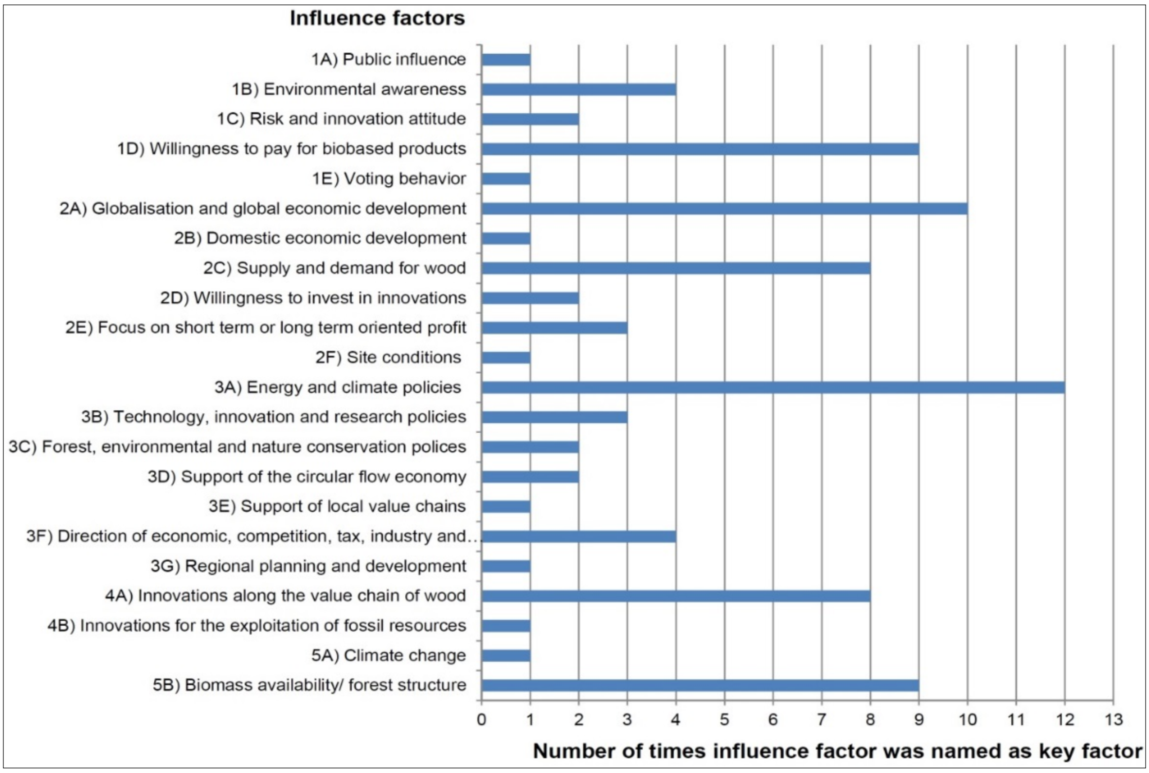

Figure 2. Ranking of influence factors by expert votes. Source: Own composition.

Figure 3 additionally shows influence factors classified as "dynamic", "active", "passive" and "buffering", based on the median value of experts' responses for each factor. Active influence factors in the upper left quadrant, such as "energy and climate policies", "globalisation and global economic development" show a strong impact on other influence factors in the system, but are only weakly affected by other influence factors themselves. This makes them particularly well suited as levers for influencing the development of the system. Dynamic influence factors, have also a strong influence on other factors, but they are also subject to strong influences—this limits their suitability as levers for deliberate interventions in the development of the bioeconomy system. However, none of the six key influence factors belong to this group. Passive influence factors in the lower right quadrant, comprising e.g., of "supply and demand for wood, are strongly influenced by other influence factors, but have low active values, and can therefore act as indicators for overall developments. Buffering influence factors, such as "willingness to pay for bio-based products" are only weakly integrated into the overall system of influence factors, although they may be important for the development of the bioeconomy in themselves. However, changes in other influence factors have a higher significance for the overall system. For constructing scenarios, active, dynamic and passive factors are particularly important, because they are strongly interconnected with other factors and therefore highly integrated into the system.

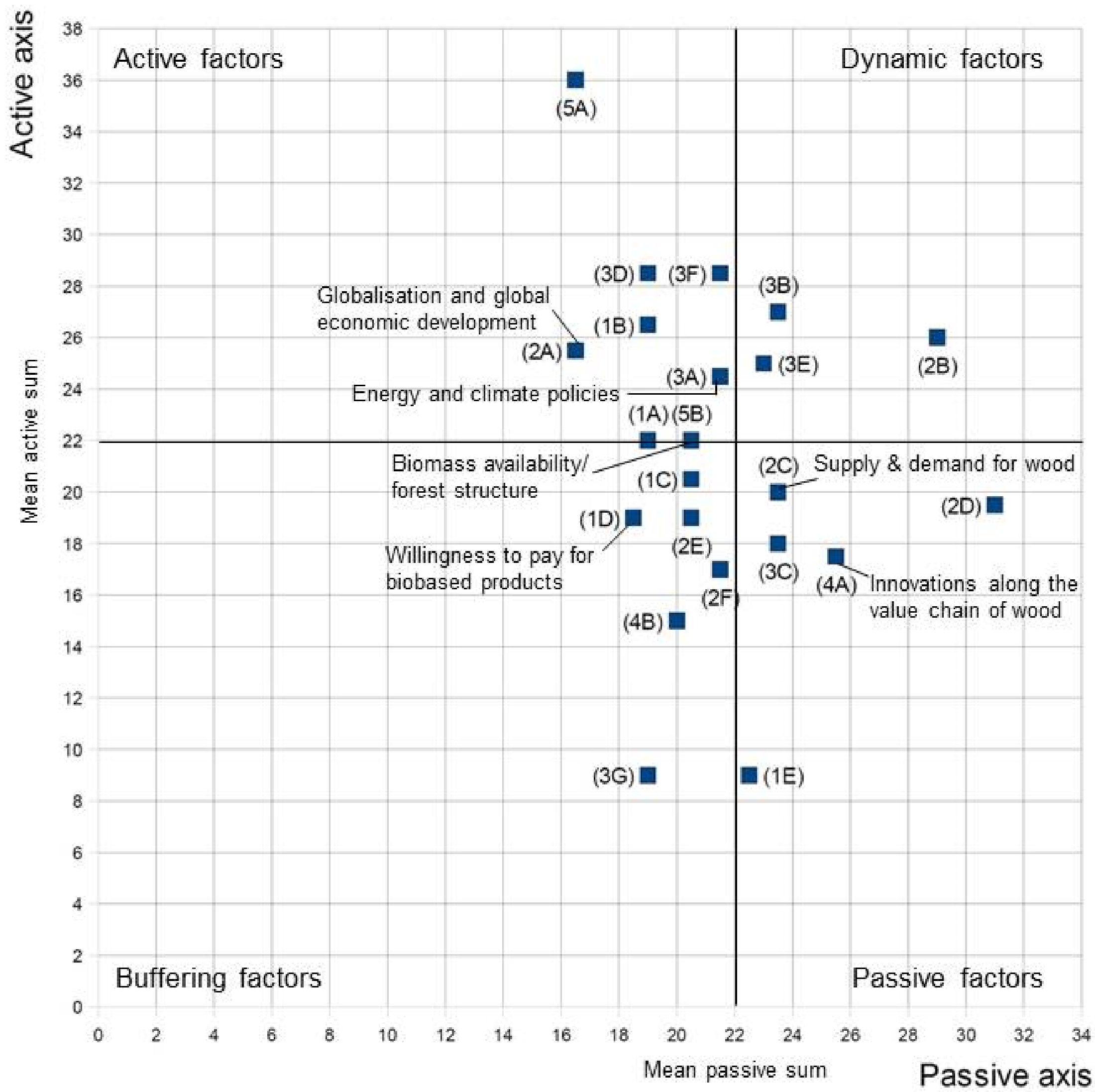

Figure 3. System grid to visualize the interaction pattern of relevant influence factors. Source: Own composition.

3.3. Third Step: Characteristics of "Key Influence Factors" and Projections

The six most important "key influence factors" are characterised in more detail by the research team, including an explanation of their role in the bioeconomy system and a definition of respective projections of each factor. For projections, extreme and opposed developments of influence factors are the most interesting, because they highlight most clearly the driving and inhibiting forces of the bioeconomy system [37]. Figure 4 gives an overview of the projections of all six key influence factors.

3.3.1. Biomass Availability and Forest Structure

Future biomass availability is crucial for bioeconomy perspectives. Decisions and strategies on future land use—increase in forest areas, expansion of agricultural land or settled areas—will determine the availability of wood biomass. Besides these decisions, site conditions, forest structures and substrate diversity provided by different sources will have an influence. Depending on technological development and legal as well as economic incentives, the use of waste products can also make an important contribution to the resource base as projected, for example, for the UK [68]. This influence factor is neither clearly characterized as "active" nor as buffering. It therefore has an influence on the development of the wood-based bioeconomy but it is not as distinct as for the other "active" key influence factors.

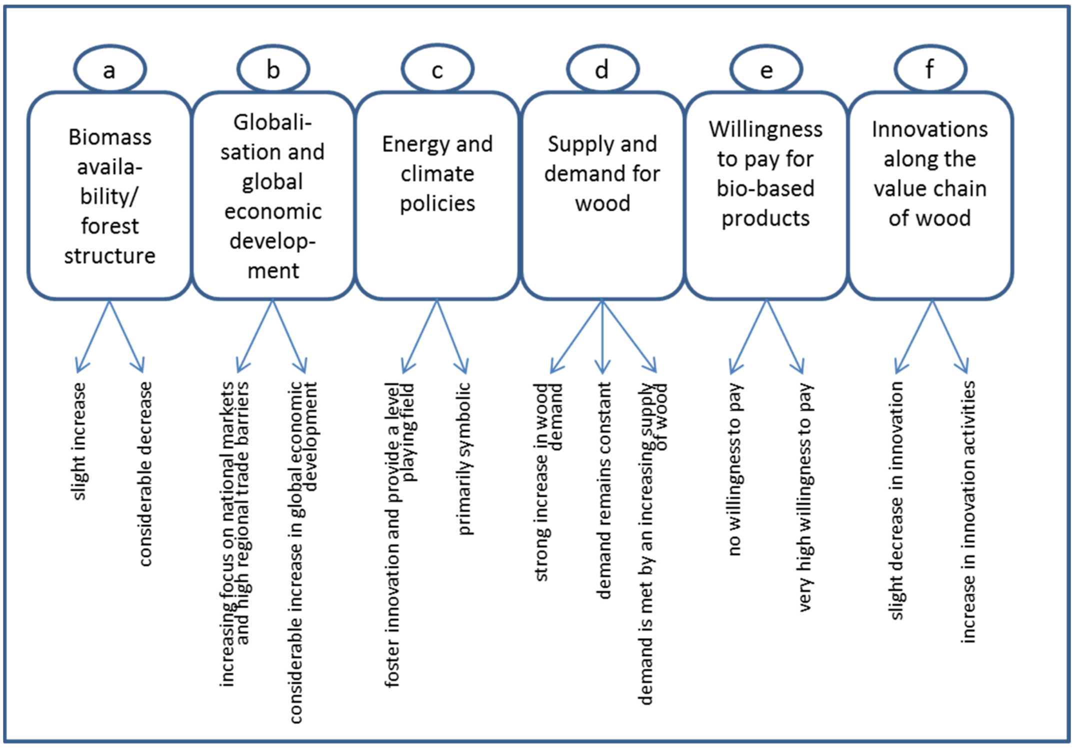

Figure 4. Overview of key influence factors and their projections. Source: Own composition based on Gausemeier *et al.* [24].

A sharp increase of high quality biomass availability is regarded as unrealistic because forests are slow-growing and changes in forest structure take time. However, a slight increase due to fast-growing trees, the utilization of scrap wood as well as changes in forest structures is regarded as possible. On the opposite side of the projections, a decrease of biomass availability is considered due to a loss of biomass through extreme weather events, a sharp increase in demand for energetic uses, and nature conservation measures. Consequently, the projections lie between a slight increase in biomass and forest structure and a considerable decrease.

3.3.2. Globalisation and Global Economic Development

National bioeconomies are heavily dependent on global economic developments in diverse ways. Long-term price increases for competing fossil inputs (e.g., the oil price), the global availability of biomass and the further development of global trade patterns as well as global (or international) regulations for the sake of climate protection or other sustainability issues affect the potential of a national bioeconomy. The influence factor is regarded as an "active" factor which means that it has the potential to influence other influence factors but is weakly influenced by other bioeconomy-related influence factors and political instruments.

An increase in the oil price, at least in the long term, is an assumption that holds for all scenarios. Opposing projections are an increasing focus on national markets and high regional trade barriers with a low trust in international networks on the one hand, and a considerable increase in global economic development including the dismantling of trade barriers for the trade of goods on the other, including raw materials, services and also intellectual property rights.

3.3.3. Energy and Climate Policies

Global, international, national and regional energy and climate policies affect the competitive position of fossil raw materials and fossil energy use and therefore strongly impact on the development of the wood-based bioeconomy. Also, the demand for energy from biomass is driven by climate change mitigation and energy policies. For instance, deployment support for renewable energies can increase the demand for bioenergy, whereas policies directed at energy efficiency improvements reduce overall energy demand. Particularly in the heating sector, where biogenic solid fuels remain the most important renewable energy source in Germany to date [69], measures such as an improved thermal insulation could contribute to significant reductions in energy demand up until 2050 [70]. Energy and climate change policies as an "active" factor have a strong impact on other factors as they determine, for example, the supply and demand for wood or the incentives for innovation.

For the scenarios, one projection assumes that effective energy and climate policies foster innovation and provide a level playing field for the competition between fossil and renewable resources, in both material and energetic applications. This includes the implementation of policy measures which increase the degree to which environmental costs of resource extraction, use and waste disposal are reflected in market prices. In an opposite projection, energy and climate policies remain primarily symbolic, failing to set effective incentives for a path transition. As a result, they have little impact on the material or energetic use of woody biomass.

3.3.4. Supply and Demand for Wood

Global to local scale economic decisions related to wood demand and supply determine how fast the wood-based bioeconomy can expand, what its structure might be and also where the limitations of expansion are. It is also to a certain extent dependent on other factors such as technological development and globalisation. Therefore, this influence factor is regarded as "passive". However, supply and demand for wood also slightly influence the bioeconomy development: the supply–demand balance, for example, determines the price for woody biomass. Because wood is mostly traded on global markets, foreign supply can influence the price for domestic biomass and displace domestic biomass production [71]. The demand from other biomass using sectors such as bioenergy also has an impact on the market equilibrium. Alternative biomass supply, for example from waste, can relax competition between biomass uses but it requires technological development and at least in Germany a significant change of regulation [45].

One plausible projection is a strong increase in wood demand that can only be satisfied to a limited extent, due to sustainability regulations that restrict imports and the removal of more woody biomass from forests. As an alternative projection, we assume that the demand is met by an increasing supply of wood, with sustainability concerns deferring to economic interests. Yet, another considered possibility is that demand remains constant due to new technological developments that allow for a more efficient use of biomass, and a focus on highly-priced specialties. Any significant decrease in demand, on the other hand, is unlikely, due to wood's energetic significance.

3.3.5. Willingness to Pay for Bio-Based Products

Consumption patterns and the willingness to pay for bio-based products are crucial, because they influence demand for bio-based products and the profitability of investing in wood-based value chains and innovation activities in the field. Labelling can increase the availability of product-related information with respect to raw material inputs and their sustainability. Social acceptance of new technologies and products in general is crucial, not only among citizens as customers but also among politicians designing policies to influence consumption patterns [72]. This key influence factor is identified as a "buffering" factor which means that it has a low interdependency with other relevant influence factors; we nonetheless decided to include it among the key factors, because of experts' assessment of its importance. The factor's comparatively low degree of systemic integration indicates that the willingness to pay for bio-based products may be difficult to influence through policies.

The projections of this factor lie between "no willingness to pay" for bio-based products and a "very high willingness to pay" driven by sustainability concerns.

3.3.6. Innovations along the Value Chain of Wood

The wood-based bioeconomy's future perspectives also depend on technological (and institutional) innovations—be they process- or product-related. Hoefnagels *et al.* [71] identify as one of the greatest uncertainties for the development of the bioeconomy in the Netherlands the costs of conversion technologies. Innovations along the value chain could reduce costs of the entire production process. As another consequence, the demand for biomass could decrease through technological innovations that require less biomass input and/or are able to utilize waste material. By closing the cascade of wood processing through new technology applications, additional value will be created. This factor is characterised as "passive", which means that innovation is driven by other influence factors, but it reflects the overall development within the wood-based bioeconomy sector.

As one projection, we assume a slight decrease in innovation, where deficiencies in the innovation system lead to weakly innovative companies. However, at the other end of the projections, we see the possibility of an increase in innovation activities which generate knowledge spillover and learning effects, supported by innovation incentives in energy and climate policies, a high willingness to pay for bio-based products and advantageous biomass availability.

3.4. Compilation of Projections into Scenarios

As derived from the status quo analysis in Section 3.1, the following key actor groups play an important role for the further development of a wood-based bioeconomy in Germany—the state, private households acting as voters and consumers as well as industry actors (companies or associations). To compile our scenarios, we define basic assumptions about the behavior of these actor groups, and combine them with projections of key factors into consistent scenarios. To simplify, we subsequently only differentiate the public and the private sector (comprising consumers/voters and companies/pressure groups), each of them with a conceivably bioeconomy-friendly or a bioeconomy-averse attitude. Hence, we obtain 2 × 2 qualitative scenarios (Figure 5).

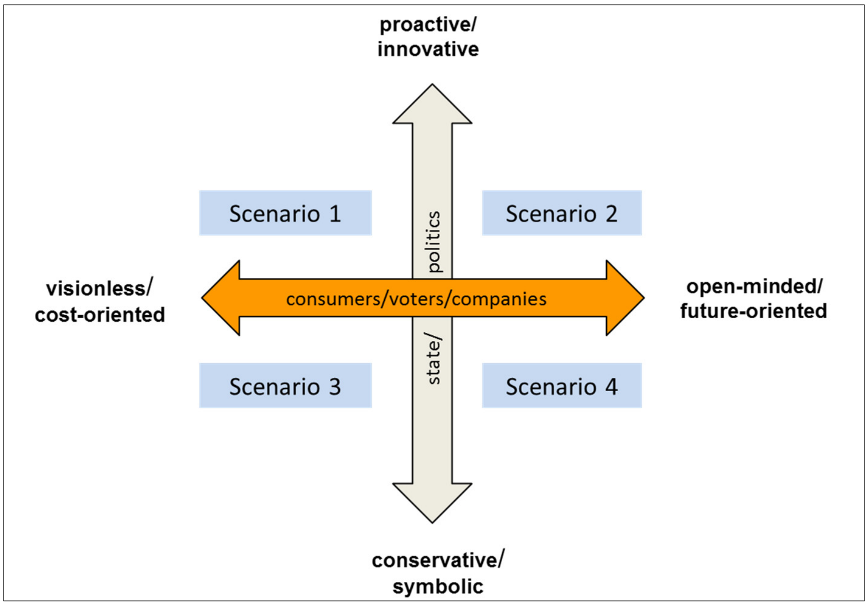

Figure 5. Definition of four scenarios. Source: Own composition.

Framework conditions set by the state (represented by policy-makers) and attitudes of voters, consumers, and companies can differ widely, as described in the following, and therefore make up the key uncertainty axis (Figure 5) around which we develop our four scenarios. The state can act between two extremes: either "proactive and innovative" or "conservative and symbolic" to avoid conflicts. The proactive state acts as a pioneer and supports innovative approaches. However, the changes are sometimes rapid and long-term consequences are overlooked. The conservative state, on the other hand, is hesitant to initiate far reaching reforms. Its orientation is along traditional structures, seeking to avoid the costs of a significant system transformation.

Societal actors appear in different roles: individuals appear as voters in political arenas and as consumers in economic arenas; industrial actors act as entrepreneurs or incumbents on markets, and may organize in interest groups to represent their interests in the political arena. The position of these actor groups might range between "open-minded and future-oriented" on the one hand and "visionless and cost-oriented" on the other hand. Open-minded and future-oriented consumers and producers see a great chance in the trend towards sustainable development. Costs are perceived as investments for the future. Producers adapt their production to this trend, but ask for governmental support for implementing a path transition away from fossil fuels. Consumers and voters accept higher prices for bio-based products but they demand more influence in decision making and quality assurance. In the other extreme, actors are visionless and cost-oriented as voters and producers leave it to political actors to solve serious environmental problems. At the same time, they are unwilling to bear additional costs arising from political support for the bioeconomy. Long-term oriented projects may be initiated by small interest groups or entrepreneurs, but are hardly relevant in practice. The majority of companies is risk-averse and reacts to signals from politics only when investments are safeguarded in the long-term. Far-reaching changes and related costs and risks of a transition are avoided and are not supported by politics.

3.5. Storylines

Based on the identification of key actors in the status quo analysis (Section 3.1), the identification and characterisation of key influence factors (Sections 3.2 and 3.3), and the definition of four scenarios (Section 3.4), the following storylines for the four scenarios of the study were created by the authors.

Scenario 1: "Government as driver": The government is sustainability-oriented and fosters the bio-economy while companies are cost-oriented, consumers are reluctant and voters are critical.

The proactive state adopts the role of a sustainability pioneer and supports innovative approaches, but these are met with various concerns on the part of the civil society (e.g., regarding competitive and sustainable forms of biomass uses). Also, consumers are reluctant and price conscious, with a low willingness to pay for innovative and bio-based products. Ambitious objectives of the government in terms of the further development of renewable energies and climate protection are placed under severe scrutiny also by companies, who are risk-averse, short-term oriented and react to political signals only when the profitability of investments is guaranteed. Although the government offers initial funding, companies avoid investments due to uncertainty concerning the supply of raw materials and the long-term reliability of government support. Hence, the rate of innovation is rather low.

The moderately increasing demand for wood-based resources is increasingly covered by imports as the amount of wood traded on the world market grows. Potential wood-based raw material sources such as private forests or secondary raw materials (e.g., waste wood, cascading uses) are barely exploited. Only a few innovative milieus, which are inspired by the government's commitment to innovation, account for a moderate increase of wood-based raw materials. These pursue a forest conversion that leads to a richer forest structure characterized by innovative combinations of local tree species in different stages of life, and that is open to new forestry methods. This has the potential of increasing the variety of substrate supply for the bioeconomy.

Scenario 2: "Trend towards sustainability": Proactive government and open-minded consumers and producers.

Ambitious renewable energy and climate protection objectives are strongly supported by civil society and companies, even if they cause higher energy and production costs. Open-minded consumers and producers are planning for the long term and see the trend towards sustainability as an opportunity. Consequently, consumers and voters accept higher costs for products and ask in return for transparency, involvement and quality assurance. Companies benefit from this trend and adapt their production to participate actively in the development of concepts for cascade use, but ask for appropriate public support. The success of innovation in this setting is very high, among other factors, because investments in research and development (R&D) are not limited to laboratory experiments but aim to become a technological standard and be broadly applied. The increasing oil price and related increasing costs for fossil-based products support the trend towards sustainability, and improve its profitability.

The government fosters the transition towards a bioeconomy by supporting an economic sustainability and corresponding political equilibrium: the high demand for wood-based raw materials and bio-based products encourages the government to implement policy instruments which support the supply and demand for innovative technologies and products. However, this leads to positive feedback loops on voter markets and among bioeconomy pressure groups, which accounts for an increasing number of measures that are hastily implemented without proper planning. The economic potential of the bioeconomy tends to be higher valued than its sustainability risks.

Innovative wood conversion methods including the use of non-local tree species are supported by the society. Changes in growing conditions as a consequence of climate change make the growth of these species possible, but also necessary. A rich wood structure and a widespread use of cascades lead to a high substrate diversity. Innovative concepts to exploit resources from private forests also help to satisfy the strong demand. Despite these efforts, the possibilities to increase the supply of wood-based raw materials for material uses are limited. This shortage is reinforced by the high demand for wood, including short rotation coppice grown on agricultural land, for energetic uses. An increasing part of the raw material demand is covered by imports; this is possible due to lenient sustainability standards regarding production conditions in export countries.

Scenario 3: "Keep going": Government and society rely on traditional values and established structures; no risk is taken to implement changes, proponents of changes carry the burden of proof for improvements.

Voters and producers are aware of the urgent environmental problems, but are unwilling to induce profound reforms and accept rising prices for fossil-based raw materials. Technological and institutional path dependencies continue to act in favor of established fossil structures, and, therefore, the carbon lock-in prevails. On the other hand, there is no broad range of alternatives available, because companies generate few innovations. Low support levels for R&D and a generally marginal interest in new technologies, processes and products contribute to this.

The objectives of climate and energy policy do not go beyond international agreements, and frequently fail to be achieved. More ambitious objectives or strategic policy approaches for supporting sustainability and the use of renewable resources remain symbolic. Because of this, the supply of wood is not actively stimulated. Concurrently, there are only small changes regarding wood structure, forest methods and management. Biomass from alternative sources, such as private forests, landscape management or secondary raw materials from cascade uses remains unexploited, because the demand for wood and alternative raw materials remains low. This leads to low substrate diversity. The extent to which external effects of the energy sector and material industries are reflected in prices is too small to induce a substitution of fossil-based products and processes and structural changes. All in all, the bioeconomy remains a niche sector.

Scenario 4: "State as obstacle": Inactive, conservative government is acting slow and tries to preserve established structures, even though society shows commitment and companies are inspired by an innovative spirit.

Open-minded and opportunity-oriented consumers with a high willingness to pay create in combination with an increasing price for fossil resources a drastic increase in demand for wood-based products. Moreover, private initiatives promote the benefits from voluntary carbon markets, although the scope of such initiatives remains limited because a supporting political framework is lacking. Producers set up long-term plans and see the trend to sustainability as an opportunity. Large companies make efforts to promote and support innovations by investments of their own. In contrast, small and medium-sized companies depend on public support that does not exist. Nonetheless, small companies succeed to some extent to set up networks and thereby generate synergies and learning effects. The high level of innovativeness on the part of the companies is faced with a reluctant government that hesitates to comply with the request for support.

Concerning efforts to protect the climate, options like natural gas and carbon capture and storage in combination with cost-efficient renewable energy technologies play an important role; a profound transition of the energy system is not undertaken. Also, when implementing sustainability reforms, the government remains oriented towards traditional structures and fears the costs of a system transition. Instead, demand for sustainability reforms is met with policies of a symbolic character, which are initiated after events of public interest. However, they are not or only partly implemented and, accordingly, do not induce lasting structural changes.

Even in cases where initially strict sustainability legislation is adopted, it is subsequently undermined by loopholes in the law. Consequently, the fossil-based "throughput economy" prevails. For example, a moderate forest conversion is conceived but never implemented. The competition for land for different energetic and material biomass applications remains moderate. However, innovative suppliers exploit private forests as sources of raw materials to meet the increasing demand for applications close to competitiveness, e.g., wood use for heating. Experiments, e.g., with new tree species, moderately increase the substrate diversity due to a low import quota.

4. Discussion: What Are the Implications of the Scenarios for Politics, Companies and Society?

As part of our scenario analysis we identified six key influence factors that shape the storylines. One of their characteristics is their diversity: They cover all societal categories, *i.e.*, society and consumers, economics and producers, politics, technology and the environment (Table 2), allowing for the conclusion that shaping the future of the wood-based bioeconomy requires a systemic perspective, rather than a focus on individual influence factors and societal categories. By improving the understanding of interactions between key influence factors, the scenarios contribute towards managing complexity, allowing for better informed decisions in politics, industry and society. Key insights are discussed in the following sections.

4.1. Benefits and Challenges for Companies and the Society

For companies, uncertainties influence investment and innovation decisions. The analysis shows that the key influence factor "innovation along the value chain of wood" with its passive interaction pattern is depending on other influence factors, namely on the influence factors "technology, innovation and research policies", but also "forest, environmental, and nature conservation policies" as well as the active support of the circular flow economy. Vandermeulen *et al.* [1] show that companies do not only ask for short-term support, but that stable political framework conditions are required over the long term. In Scenario 4 "State as obstacle", companies are more active, even without state support. Here, the development is driven by larger companies with their own R&D departments, who engage in innovation to take a lead in sustainable consumption markets and are willing to bear associated risks. In this scenario, smaller companies can still profit from spill-over effects of innovations and also from positive effects such as an increase in the amount of contracts as suppliers.

Similarly, consumers often have little information about the risks and uncertainties associated with different types of resource uses and this directly influences their acceptance of new products. Not surprisingly, "willingness to pay for bio-based products" is a key influence factor that determines the demand for bio-based products. However, as Figure 3 shows, it is not linked strongly to the other influence factors—it neither influences them greatly nor is subject to major influences itself. The only factors that have an impact are the influence factors "public influence", such as demand for and support of sustainability policies and bio-based products as well as "domestic economic development" (see Figure 1). An individual analysis and concept is required to enhance the "willingness to pay for bio-based products". Best practice examples can be derived from supporting the increase of organic products through certification and information campaigns.

Information generation, availability and distribution is therefore crucial in order to increase the demand for woody bio-based products, but it might also require a certain individual initiative as well as willingness to act as a self-determined consumer. Scenario 1 also demonstrates that without consumers' and voters' support, the impact of political action is limited—the acceptance of products and willingness to pay cannot be neglected, and are not easily changeable. Also, without voter support, there is a limit to the long-term credibility of policy initiatives, which may be discarded as political priorities and majorities change. Also, support by industry interest groups is necessary to guard policies and initiate path changes from a roll back. Here, advocacy coalitions of companies and societal groups supporting the bioeconomy can play an important role, to counterbalance the political weight of actors invested in fossil-based pathways [73,74].

4.2. The State's Role in Balancing Stability and Flexibility under Uncertainty

Climate change, the discovery of new fossil fuel resources, biomass availability and impacts of international conflicts are uncertainties that will influence societies, politics and, consequently, the bioeconomy. Many of these uncertainties can be moderated by politics only to a certain extent. What is important is that the state provides stable political framework conditions, which provide guidance for a path transition from a fossil fuel-based "throughput-economy" towards a renewable resources-based circular flow economy. Bioenergy policy developments in recent years can serve as an illustration for trade-offs between creating stable conditions for companies and the need for flexibility to remain capable in policy design. For example, the EU Renewable Energy Directive's 10% target for renewable energy sources in the transport sector and its implementation into member states' laws created a strong demand for crop-based biofuels, which was followed by an intense debate about sustainability risks. However, subsequent policy adjustments such as the implementation of the EU commission's 2012 proposal to cap the contribution of crop-based biofuels to the target have significantly increased uncertainty for investors. In dealing with uncertainties, a combination of reliable policy signals and proactive consumers and companies, who can make use of decentralized knowledge and trial and error processes, is likely to perform best (Scenario 2). What politics can do throughout all scenarios is to improve the coordination of existing policies which are relevant for the bioeconomy. Interdependencies of the bioeconomy with a range of other policy fields is high—besides the already mentioned energy and climate policies and international trade agreements, many other policy fields either contribute or conflict with the expansion of the wood-based bioeconomy. Regional planning, forest policies and nature conservation policies are only a few examples. The lack of an overarching "bioeconomy policy" means that the bioeconomy remains a by-product of other policies. Besides an improved coordination of policy areas, it is necessary to examine in detail policy adjustment needs for the individual policy areas, in order to provide an effective governance framework [44]. Firstly, with an increasing demand for domestically produced and imported wood, the ability of existing forest, conversation and trade policies to safeguard sustainability must be evaluated. At the same time, design and implementation of waste regulation may need to be adapted to increase availability of secondary resources and set incentives for circular resource flow concepts [45]. Secondly, support for R&D, knowledge exchange and niche creation are needed to promote the development and diffusion of innovative bioeconomy technologies and products (see Section 4.1). Thirdly, climate policy instruments in particular need to set incentives for substituting fossil fuel-based production inputs for bio-based ones.

Given the prevalent role of uncertainties, we conclude that a gradual implementation of policy instruments to improve the position of the bioeconomy is more promising instead of a rushed introduction of several (potentially unsupported) new instruments with unknown effects. A gradual approach does not only allow for learning, but also for the formation of political constituencies, which provide support for a path transition [73,75]. Also, to create a reliable policy framework for a sustainable path transition, a mix of instruments is required. While R&D support is an important component of bioeconomy policy, to stimulate the supply of innovative technologies, it needs to be combined with instruments that create demand for bio-based products and processes [15,76,77]. To be effective, demand-pull policies need to encompass two dimensions: for one, they need to directly support the diffusion of innovative products and processes, e.g., by creating niches through public procurement or labelling; but also, policies are needed which increase the costs of conventional alternatives based on fossil fuels or more energy- and GHG-intensive materials, to indirectly support the diffusion of bio-based options close to technological maturity.

4.3. Resource Availability and Distribution

The availability of resources is a crucial bottleneck for the development of the wood-based bioeconomy. The key influence factor "Biomass availability/forest structure" is influenced by initiatives by policy makers and market actors, but it is also subject to external factors, such as climate change impacts. The potential of expanding the material use of wood is at present limited, one reason being its competition with energetic uses which in Germany have been fostered by the Renewable Energy Sources Act (EEG) in the electricity sector [50], and the Renewable Energy Heating Act (EEWärmeG) in the heating sector [78]. The competition between energetic and material uses is currently distorted, because comparable deployment support for material uses does not yet exist. Increasing demand for wood leads to rising wood prices [40]; this in turn decreases the competitiveness of wood-based products and processes compared to fossil-based ones. However, emerging new innovative technologies and processes may reduce pressure on resources, if they allow for a more efficient use of land and biomass [79]. Increasing efforts towards a circular economy and the use of cascade production also prove important in this regard. The uptake and further development of alternative resources such as waste products could further relieve competition for biomass. The recycling potential and characteristics of waste products that could serve as substitutes for wood are not extensively researched yet and, at present, regulation of waste recycling is not clearly enough defined to allow for the widespread use of waste as a new resource [45]. Research and regulation are key components for unlocking the illustrated potential. Besides the stimulation of local and regional biomass availability, imports can play a role in expanding the resource base. However, the effectiveness of governance options for safeguarding large-scale wood imports is associated with considerable uncertainties [80] (see Section 4.4).

4.4. Sustainability Concerns and the Bioeconomy

The claim that the bioeconomy could solve sustainability problems by simply substituting fossil resources is a myth [81]. Correspondingly, even in the most optimistic Scenario 2, uncertainties remain about how sustainable the bioeconomy is and could be. For the wood-based bioeconomy, several questions arise, such as: how much wood can be taken from domestic forests without compromising its natural regeneration? How much wood should be imported, of what quality should it be and what sustainability standards should apply? And if biomass availability is increased by planting new or fast-growing forests, are genetically modified organisms accepted? Bioenergy policy developments in Germany and the EU illustrate how a predominantly positive perception of environmental impacts can change over time [82]. Solving "wicked" problems is not only a bioeconomy challenge but has to be dealt with in many environment-related settings [83,84].

For all scenarios, a discussion is required on how to define indicators for a sustainable development of the bioeconomy sector and its resource base; however, sustainability indicators are also required for competing fossil fuel-based industries. At present, the bioeconomy sustainability discussion is still at its beginning [85]. The bioeconomy—and especially the wood-based bioeconomy—itself will not be able to solve today´s sustainability problems, but it can be part of a comprehensive global strategy towards sustainable development, including the further development of renewable energies [79].

We conclude that even though the wood-based bioeconomy holds a certain potential to contribute to a more sustainable development of the economy, its sustainability is by no means guaranteed; also, bioeconomy concepts need to be embedded into a broader sustainable development context. Moreover, sustainability constraints need to be addressed through adequate regulatory framework conditions (e.g., environmental or forestry law) and taken into account in the design of policy instruments that increase demand for bio-based products.

4.5. International Ramifications

The key influence factor "energy and climate policies" can directly be shaped by policy makers, although coordination is required between national and European governance levels. From the scenario analysis, we can also conclude that the development of the wood-based bioeconomy in Germany is not independent of the development of the global economy. However, the key influence factor "globalisation and global economic development" in particular can hardly be influenced by national-level bioeconomy policy makers. Among other factors, experts named climate change and advances in the exploration of fossil resources as important influences (see Figure 1), but the future development of these factors is subject to uncertainties.

The amount of wood provided by the world market will influence demand and supply on national markets. Furthermore, developments on the global markets with regard to amount and quality of products will be decisive for the development of the wood-based bioeconomy, for example, by impacting on innovation activities. Also, policy developments at the European or global level e.g., with regard to climate policies can have an important impact on conditions for bioeconomy development.

5. Conclusions

Our analysis developed four different scenarios for the German wood-based bioeconomy in 2050. Based on the scenario analysis, we could identify key components which influence the future development of the wood-based bioeconomy. Politics play a key role in fostering the development of a sustainable bioeconomy and decreasing uncertainties for market actors, but are limited in their impact whenever consumers and producers do not accept new policies and willingness to pay for bio-based products remains low. Therefore, it is important that sustainability issues are made transparent and are openly discussed with stakeholders [80].

Furthermore, international (climate) politics and globalisation have a great influence on bioeconomy development, but can often hardly be influenced by national politics. The dependence of the general bioeconomy on natural resources increases uncertainties with regard to long-term availability. The wood-based bioeconomy is still labelled as sustainable as such, but with increasing use of biomass this has to be questioned, as exemplified by the boost of the energetic use of biomass. Hence, sustainability issues and bioeconomy development have to be discussed in close connection with each other.

We conclude from our analysis that the state has to define long-term framework conditions for the development of the wood-based bioeconomy, which need to be coordinated with both global economic developments and domestic political approval. Economic, societal and political arenas have to be incorporated at the same time to secure voters´ approval and consumers´ acceptance as well as economic opportunities. At the same time, it needs to be taken into account that a path transition towards the bioeconomy as such cannot and will not guarantee that sustainability requirements are met. Therefore, policies promoting material and energetic biomass uses need to be designed with sustainability constraints and associated uncertainties in mind, and be framed by initiatives to improve the sustainability of land use independent of the sector biomass-based products are used in. Keeping all these aspects in mind, we conclude that the wood-based bioeconomy has a certain potential to develop further and may contribute to a path transition from a fossil resource-based economy towards a circular flow economy based on renewable resources, if adequate political framework conditions are implemented and they meet voter support, if consumers exhibit an enhanced willingness to pay for bio-based products, and if, among companies, a chance-oriented advocacy collation of bioeconomy supporters dominates over proponents of fossil pathways.

Supplementary Materials: The following are available online at www.mdpi.com/http://www.mdpi.com/2071-1050/8/1/98/s1, Table S1: List of analysed scenarios and identified influence factors.

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References

1. Vandermeulen, V.; van der Stehen, M.; Stevens, C.V.; van Huylenbroeck, G. Industry expectations regarding the transition towards a biobased economy. *Biofuels Bioprod. Biorefining* **2012**, *6*, 453–464. [CrossRef]
2. European Commission (EC). Communication from the Commission to the European Parliament, the Council, the European Economic and Social Committee and the Committee of the Regions. Innovating for Sustainable Growth: A Bioeconomy for Europe. {SWD(2012) 11 final}. Available online: ec.europa.eu/research/bio economy/pdf/official-strategy_en.pdf (accessed on 7 April 2015).
3. Bundesministerium für Bildung und Forschung (BMBF); Bundesministerium für Ernährung und Landwirtschaft (BMEL). *Bioökonomie in Deutschland—Chancen für eine Biobasierte und Nachhaltige Zukunft*; Bonn: Berlin, Germany, 2014; Available online: www.bmbf.de/pub/Biooekonomie-in-Deutschland_001.pdf (accessed on 7 April 2015). (In German)
4. Bundesministerium für Ernährung und Landwirtschaft (BMEL). Nationale Politikstrategie Bioökonomie—Nachwachsende Ressourcen und Biotechnologische Verfahren als Basis für Ernährung, Industrie und Energie. Available online: https://www.bmbf.de/files/BioOekonomiestrategie.pdf (accessed on 18 January 2016). (In German)
5. McCormick, K.; Kautto, N. The bioeconomy in Europe: An overview. *Sustainability* **2013**, *5*, 2589–2608. [CrossRef]
6. Staffas, L.; Gustavsson, M.; McCormick, K. Strategies and policies for the bioeconomy and bio-based economy: An analysis of official national approaches. *Sustainability* **2013**, *5*, 2751–2769. [CrossRef]
7. Michigan State University (MSU) Product Center and Shepherd Advisors. Future Scenarios for Michigan's Bioeconomy: Planning Your Strategic Responses. Available online: http://productcenter.msu.edu/uploads/files/Future Scenarios for Michigans Bioeconomy.pdf (accessed on 18 January 2016).
8. Edwards, R.; Szekeres, S.; Neuwahl, F.; Mahieu, V. Biofuels in the European Context: Facts and Uncertainties. Available online: ec.europa.eu/dgs/jrc/downloads/jrc_biofuels_report.pdf (accessed on 7 April 2015).
9. Jenkins, J.D. Political economy constraints on carbon pricing policies: What are the implications for economic efficiency, environmental efficacy, and climate policy design? *Energy Policy* **2014**, *69*, 467–477. [CrossRef]
10. Lahl, U. Bioökonomie für den Klima—Und Ressourcenschutz—Regulative Handlungskorridore. Study on behalf of NABU. Available online: https://www.nabu.de/imperia/md/content/nabude/gentechnik/studien/140821-nabu-biooekonomie-studie_2014.pdf (accessed on 30 October 2015). (In German).
11. Unruh, G.C. Understanding carbon lock-in. *Energy Policy* **2000**, *28*, 817–830. [CrossRef]
12. Unruh, G.C. Escaping carbon lock-in. *Energy Policy* **2002**, *30*, 317–325. [CrossRef]
13. Fischer, C.; Newell, R.G. Environmental and technology policies for climate mitigation. *J. Environ. Econ. Manag.* **2008**, *55*, 142–162. [CrossRef]
14. Jaffe, A.B.; Newell, R.G.; Stavins, R.N. A tale of two market failures: Technology and environmental policy. *Ecol. Econ.* **2005**, *54*, 164–174. [CrossRef]

15. Grubler, A.; Aguayo, F.; Gallagher, K.; Hekkert, M.; Jiang, K.; Mytelka, L.; Neij, L.; Nemet, G.; Wilson, C. Policies for the Energy Technology Innovation System (ETIS). In *Global Energy Assessment—Toward a Sustainable Future*; Cambridge University Press: Cambridge, UK; New York, NY, USA; The International Institute for Applied Systems Analysis: Laxenburg, Austria, 2012; pp. 1665–1744.
16. Purkus, A.; Röder, M.; Gawel, E.; Thrän, D.; Thornley, P. Handling uncertainty in bioenergy policy design—A case study analysis of UK and German bioelectricity policy instruments. *Biomass Bioenergy* **2015**, *79*, 64–79. [CrossRef]
17. March, H.; Therond, O.; Leenhardt, D. Water futures: Reviewing water-scenario analyses through an original interpretative framework. *Ecol. Econ.* **2012**, *82*, 126–137. [CrossRef]
18. Priess, J.A.; Hauck, J. Integrative scenario development. *Ecol. Soc.* **2014**, *19*, 12. [CrossRef]
19. Biggs, R.; Raudsepp-Hearne, C.; Atkinson-Palombo, C.; Bohensky, E.; Boyd, E.; Cundill, G.; Fox, H.; Ingram, S.; Kok, K.; Spehar, S.; *et al*. Linking futures across scales: A dialog on multiscale scenarios. *Ecol. Soc.* **2007**, *12*, 17.
20. Alkemade, R.; van Oorschot, M.; Miles, L.; Nellemann, C.; Bakkenes, M.; ten Brink, B. GLOBIO3: A framework to investigate options for reducing global terrestrial biodiversity loss. *Ecosystems* **2009**, *12*, 374–390. [CrossRef]
21. Leadley, P.W.; Krug, C.B.; Alkemade, R.; Pereira, H.M.; Sumaila, U.R.; Walpole, M.; Marques, A.; Newbold, T.; Teh, L.S.L.; van Kolck, J.; *et al*. *Progress towards the Aichi Biodiversity Targets: An Assessment of Biodiversity Trends, Policy Scenarios and Key Actions*; Secretariat of the Convention on Biological Diversity: Montreal, QC, Canada, 2014.
22. Maes, J.; Hauck, J.; Paracchini, M. L.; Ratamäki, O.; Hutchins, M.; Termansen, M.; Furman, E.; Pérez-Soba, M.; Braat, L. Mainstreaming ecosystem services into EU policy. *Curr. Opin. Environ. Sustain.* **2013**, *5*, 128–134. [CrossRef]
23. The Organisation for Economic Co-operation and Development (OECD). *What External Factors Will Drive the Bioeconomy to 2030? The Bioeconomy to 2030: Designing a Policy Agenda*; OECD Publishing: Paris, France, 2009.
24. Gausemeier, J.; Fink, A.; Schlake, O. Scenario Management: An approach to develop future potentials. *Technol. Forecast. Soc. Chang.* **1998**, *59*, 111–130. [CrossRef]
25. Rounsevell, M.D.A.; Metzger, M.J. Developing qualitative scenario storylines for environmental change assessment. *Wiley Interdiscipl. Rev. Clim. Chang.* **2010**, *1*, 606–619. [CrossRef]
26. Government Office for Science. Collection Foresight Projects. Available online: https://www.gov.uk/government/collections/foresight-projects (accessed on 18 January 2016).
27. Steinmetz, J.; Bennett, C.; Håkonsson, D.D. A practitioner's view of the future of organization design: Future trends and implications for Royal Dutch Shell. *J. Organ. Des.* **2012**, *1*, 7–11.
28. Purkus, A.; Barth, V. Geothermal power production in future electricity markets—A scenario analysis for Germany. *Energy Policy* **2011**, *39*, 349–357. [CrossRef]
29. Carus, M.; Dammer, L. Food or non-food: Which agricultural feedstocks are best for industrial uses? *Ind. Biotechnol.* **2013**, *9*, 171–176. [CrossRef]
30. Kajaste, R. Chemicals from biomass—Managing greenhouse gas emissions in biorefinery production chains—A review. *J. Clean. Prod.* **2014**, *75*, 1–10. [CrossRef]
31. Limayem, A.; Ricke, S.C. Lignocellulosic biomass for bioethanol production: Current perspectives, potential issues and future prospects. *Prog. Energy Combust. Sci.* **2012**, *38*, 449–467. [CrossRef]
32. Bundesministerium für Bildung und Forschung (BMBF). Nationale Forschungsstrategie BioÖkonomie 2030. Unser Weg zu einer bio-basierten Wirtschaft. Available online: https://www.bmbf.de/pub/biooekonimie.pdf (accessed on 26 October 2015). (In German)
33. Bioeconomy Cluster. Available online: http://en.bioeconomy.de (accessed on 18 January 2016).
34. Özkaynak, B.; Rodriguez-Labajos, B. Mutli-scale interaction in local scenariobuilding: A methodological framework. *Futures* **2012**, *42*, 995–1006.
35. Verband der Chemischen Industrie e.V. (VCI). Die Deutsche Chemische Industrie 2030. VCI-Prognos-Studie. Available online: https://www.vci.de/vci/downloads-vci/publikation/langfassung-prognos-studie-30-01-2013.pdf (accessed on 7 April 2015).
36. Steinmüller, K.; Schulz-Montag, B.; Veenhoff, S. Waldzukünfte 2100. Szenarioreport. Available online: http://www.z-punkt.de/fileadmin/be_user/D_CorporateForesight/Wald2100_Szenreport_090603_kons.pdf (accessed on 7 April 2015). (In German)

37. Von Reibnitz, U. Szenario-Technik: Instrumente für die unternehmerische und persönliche Erfolgsplanung. Gabler Verlag: Wiesbaden, Germany, 1992. (In German)
38. Mißler-Behr, M. Auf der Suche nach Zukunftsbildern. Eine Regelbasis zur Szenarienauswahl. In *Szenariotechnik—Vom Umgang mit der Zukunft*; Wilms, F.E.P., Ed.; Haupt Verlag: Bern, Switzerland, 2006; pp. 215–240. (In German)
39. Fachagentur Nachwachsende Rohstoffe e.V. (FNR). Marktanalyse Nachwachsende Rohstoffe. Available online: http://fnr.de/marktanalyse/marktanalyse.pdf (accessed on 14 January 2016). (In German)
40. Mantau, U. *Holzrohstoffbilanz Deutschland—Entwicklungen und Szenarien des Holzaufkommens und der Holzverwendung von 1987 bis 2015*; Universität Hamburg: Hamburg, Germany, 2012. (In German)
41. Dieter, M. Volkswirtschaftliche Betrachtung von holzbasierter Wertschöpfung in Deutschland. In *Waldstrategie 2020 Tagungsband zum Symposium des BMELV, 10.-11. Dez. 2008, Berlin*; Seintsch, B., Dieter, M., Eds.; Landbauforschung—vTI Agriculture and Forestry Research: Braunschweig, Germay, 2009; Volume 327, pp. 37–46. (In German)
42. Bundesministerium für Ernährung, Landwirtschaft und Verbraucherschutz (BMELV). *Aktionsplan zur stofflichen Nutzung nachwachsender Rohstoffe*; BMELV: Bonn, Germany, 2009. (In German)
43. Bundesministerium für Umwelt, Naturschutz und Reaktorsicherheit (BMU); Bundesministerium für Ernährung, Landwirtschaft und Verbraucherschutz (BMELV). *Nationaler Biomasseaktionsplan für Deutschland—Beitrag der Biomasse für eine Nachhaltige Energieversorgung*; BMU: Berlin, Germany; BMELV: Bonn, Germany, 2010. (In German)
44. Pannicke, N.; Gawel, E.; Hagemann, N.; Purkus, A.; Strunz, S. The political economy of fostering a wood-based bioeconomy in Germany. *Ger. J. Agric. Econ.* **2015**, *64*, 224–243.
45. Ludwig, G.; Köck, W.; Tronicke, C.; Gawel, E. Der Rechtsrahmen für die Bioökonomie in Deutschland. *Die Öffentliche Verwaltung (DÖV)* **2015**, *68*, 41–54. (In German)
46. Gawel, E.; Purkus, A. The role of energy and electricity taxation in the context of the German energy transition. *Z. Energiewirtschaft* **2015**, *39*, 77–103. [CrossRef]
47. Hu, J.; Crijns-Grausa, W.; Lamb, L.; Gilbert, A. Ex-ante evaluation of EU ETS during 2013–2030: EU-internal abatement. *Energy Policy* **2015**, *77*, 152–163. [CrossRef]
48. Isenmann, R.; von Hauff, M. *Industrial Ecology: Mit Ökologie Zukunftsorientiert Wirtschaften*; Elsevier: München, Germany, 2007. (In German)
49. North, D.C. *Institutions, Institutional Change and Economic Performance*; Cambridge University Press: Cambridge, UK, 1990.
50. Purkus, A.; Gawel, E.; Deissenroth, M.; Nienhaus, K.; Wassermann, S. Market integration of renewable energies through direct marketing—lessons learned from the German market premium scheme. *Energy Sustain. Soc.* **2015**, *5*, 1–13. [CrossRef]
51. German Institute for Standardization. *DIN EN 15440:2011-05. Solid Recovered Fuels—Methods for the Determination of Biomass Content*; German Version EN 15440:2011; Beuth Verlag GmbH: Berlin, Germany, 2011.
52. German Institute for Standardization. *DIN EN 14995:2007-03. Plastics—Evaluation of Compostability—Test Scheme and Specifications*; German Version EN 14995:2006; Beuth Verlag GmbH: Berlin, Germany, 2007.
53. German Institute for Standardization. *Bio-Based Products—Sustainability Criteria*; German Version FprEN 16751:2015; Beuth Verlag GmbH: Berlin, Germany, 2015.
54. German Institute for Standardization. *Bio-Based Products—Life Cycle Assessment*; German Version EN 16760:2015; Beuth Verlag GmbH: Berlin, Germany, 2015.
55. Sheppard, A.W.; Gillespie, I.; Hirsch, M.; Begley, C. Biosecurity and sustainability within the growing global bioeconomy. *Curr. Opin. Environ. Sustain.* **2011**, *3*, 4–10. [CrossRef]
56. Die Bundesregierung. Perspektiven für Deutschland—Unsere Strategie für eine nachhaltige Entwicklung. Available online: http://www.bundesregierung.de/Content/DE/_Anlagen/Nachhaltigkeit-wiederhergestellt/perspektiven-fuer-deutschland-langfassung.pdf?__blob=publicationFile (accessed on 30 October 2015). (In German)
57. Bundesministerium für Bildung und Forschung (BMBF). Ideen. Innovation. Wachstum—Hightech-Strategie 2020 für Deutschland. Available online: https://www.bmbf.de/pub/hts_2020.pdf (accessed on 26 October 2015).

58. Bundesministerium für Wirtschaft und Technologie (BMWI). Forschung für eine Umweltschonende, Zuverlässige und Bezahlbare Energieversorgung—Das 6. Energieforschungsprogramm der Bundesregierung. Available online: https://www.bmwi.de/BMWi/Redaktion/PDF/E/6-energieforschungsprogramm-der-bundesregierung,property=pdf,bereich=bmwi2012,sprache=de,rwb=true.pdf (accessed on 18 January 2016). (In German)
59. Bundesministerium für Bildung und Forschung (BMBF). Deutschlands Rolle in der Globalen Wissensgesellschaft Stärken—Strategie der Bundesregierung zur Internationalisierung von Wissenschaft und Forschung. Available online: www.bmbf.de/pub/Internationalisierungsstrategie.pdf (accessed on 18 January 1016). (In German)
60. Bundesministerium für Bildung und Forschung (BMBF). Rahmenprogramm Gesundheitsforschung der Bundesregierung. Available online: http://www.gesundheitsforschung-bmbf.de/_media/Gesundheitsforschungsprogramm.pdf (accessed on 26 October 2015). (In German)
61. Bundesministerium für Umwelt, Naturschutz und Reaktorsicherheit (BMU). National Strategy on Biological Diversity. Available online: https://biologischevielfalt.bfn.de/fileadmin/NBS/documents/Veroeffentlichungen/BMU_Natio_Strategie_en_bf.pdf (accessed on 10 November 2015).
62. Bundesministerium für Ernährung, Landwirtschaft und Verbraucherschutz (BMELV). *Waldstrategie 2020—Nachhaltige Waldbewirtschaftung—Eine gesellschaftliche Chance und Herausforderung*; BMELV: Bonn, Germany, 2011. (In German)
63. Bundesministerium für Ernährung, Landwirtschaft und Verbraucherschutz (BMELV). Verstärkte Holznutzung—Zugunsten von Klima, Lebensqualität, Innovationen und Arbeitsplätzen (Charta für Holz). Available online: http://www.dhwr.de/fileadmin/user_upload/downloads/ChartaFuerHolz.pdf (accessed on 26 October 2015). (In German)
64. Bundesministerium für Verkehr, Bau und Stadtentwicklung (BMVBS). *Erlass zur Beschaffung von Holzprodukten*; BMVBS: Berlin, Germany, 2011. (In German)
65. Krippner, R. Untersuchungen zu Einsatzmöglichkeiten von Holzleichtbeton im Bereich von Gebäudefassaden. Ph.D. Thesis, Technische Universität München, Munich, Germany, 8 March 2004. (In German)
66. Gärtner, S.; Hienz, G.; Keller, H.; Müller-Lindenlauf, M. *Gesamtökologische Bewertung der Kaskadennutzung von Holz: Umweltauswirkungen Stofflicher und Energetischer Holznutzungssysteme im Vergleich*; IFEU Heidelberg: Heidelberg, Germany, 2013. (In German)
67. De Besi, M.; McCormick, K. Towards a bioeconomy in Europe: National, regional and industrial strategies. *Sustainability* **2015**, *7*, 10461–10478. [CrossRef]
68. Welfe, A.; Gilbert, P.; Thornley, P. Increasing biomass resource availability through supply chain analysis. *Biomass Bioenergy* **2014**, *70*, 249–266. [CrossRef]
69. Fachagentur Nachwachsende Rohstoffe e.V. (FNR). Bioenergy in Germany: Facts and Figures. January 2014. Available online: https://mediathek.fnr.de/media/downloadable/files/samples/b/a/basisdaten_9x16_2013_engl_web.pdf (accessed on 9 December 2015).
70. Prognos AG; EWI—Institute of Energy Economics at the University of Cologne; GWS—Gesellschaft für Wirtschaftliche Strukturforschung. Entwicklung der Energiemärkte—Energiereferenzprognose. Projekt Nr. 57/12 des Bundesministeriums für Wirtschaft und Technologie. Available online: http://www.bmwi.de/DE/Mediathek/publikationen,did=644920.html (accessed on 6 January 2016). (In German)
71. Hoefnagels, R.; Dornburg, V.; Faaij, A.; Banse, M. Analysis of the Economic Impact of Large-Scale Deployment of Biomass Resources for Energy and Materials in The Netherlands. Available online: edepot.wur.nl/164540 (accessed on 7 April 2015).
72. Peck, P.; Bennett, S.; Bissett-Amess, R.; Lenhart, J.; Mozaffarian, H. Examining understanding, acceptance, and support for the biorefinery concept among EU policy-makers. *Biofuels Bioprod. Biorefining* **2009**, *3*, 361–383. [CrossRef]
73. Dewatripont, M.; Roland, G. The design of reform packages under uncertainty. *Am. Econ. Rev.* **1995**, *85*, 1207–1223.
74. Lehmann, P.; Creutzig, F.; Ehlers, M.-H.; Friedrichsen, N.; Heuson, C.; Hirth, L.; Pietecker, R. Carbon lock-out: Advancing renewable energy policy in Europe. *Energies* **2012**, *5*, 323–354. [CrossRef]
75. Wei, S.-J. Gradualism versus Big Bang: Speed and sustainability of reforms. *Can. J. Econ.* **1997**, *30*, 1234–1247. [CrossRef]

76. Borrás, S.; Edquist, C. The choice of innovation policy instruments. *Technol. Forecast. Soc. Chang.* **2013**, *80*, 1513–1522. [CrossRef]
77. Foxon, T.J.; Gross, R.; Chase, A.; Howes, J.; Arnall, A.; Anderson, D. UK innovation systems for new and renewable energy technologies: Drivers, barriers and systems failures. *Energy Policy* **2005**, *33*, 2123–2137. [CrossRef]
78. Gawel, E.; Loßner, M.; Herbes, C. EEWärmeG—Hindernisse und Potenziale im Wärmemarkt für Biomethan. *Energiewirtschaftliche Tagesfragen* **2013**, *63*, 48–53. (In German)
79. Piotrowski, S.; Carus, M.; Essel, R. Global bioeconomy in the conflict between biomass supply and demand. *Nova Pap.* **2015**, *7*, 1–14. [CrossRef]
80. Upham, P.; Riesch, H.; Tomei, J.; Thornley, P. The sustainability of forestry biomass supply for EU bioenergy: A post-normal approach to environmental risk and uncertainty. *Environ. Sci. Policy* **2011**, *14*, 510–518. [CrossRef]
81. Pfau, S.F.; Hagens, J.E.; Dankbaar, B.; Smits, A.J.M. Visions of sustainability in bioeconomy research. *Sustainability* **2014**, *6*, 1222–1249. [CrossRef]
82. Londo, M.; Deurwaarder, E. Developments in EU biofuels policy related to sustainability issues: Overview and outlook. *Biofuels Bioprod. Biorefining* **2007**, *1*, 292–302. [CrossRef]
83. Batie, S.S. Wicked problems and applied economics. *Am. J. Agric. Econ.* **2008**, *90*, 1176–1191.
84. McCann, L. Transaction costs and environmental policy design. *Ecol. Econ.* **2013**, *88*, 253–262. [CrossRef]
85. Fritsche, U.R.; Iriarte, L. Sustainability criteria and indicators for the bio-based economy in Europe: State of discussion and way forward. *Energies* **2014**, *7*, 6825–6836. [CrossRef]