

Article

Societal Evaluation of Bioeconomy Scenarios for Germany

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Abstract: Transitioning to a bio-based economy is widely perceived as a necessary way to tackle climate change and other key environmental challenges. Given the major socio-economic consequences that such a transition entails for people's everyday lives, it is crucial to take account of citizens' perceptions and levels of acceptance of these changes. This study applies a holistic approach to gain an understanding of how citizens in Germany assess possible developments associated with transitioning to a bioeconomy. We developed three future scenarios modelling the impacts on people's day-to-day lives of adopting different elements of a bioeconomy and of replacing fossil resources with biogenic resources to a lesser or greater extent by 2050. German citizens were asked to evaluate the different scenarios through a quantitative online survey. Although the respondents largely preferred the scenario of "Bioeconomy Change" entailing the most substantial changes in resource use, many also expressed concerns about the possible negative socio-economic effects of this scenario, including fears of increased product prices, declining living standards, and greater social injustice. The results show that younger people and women are more in favour of changes towards a bioeconomy than men and older people. Since the acceptance of bio-technical innovations increases with greater knowledge about such innovations and their usefulness, the transformation process must make use of sound communication strategies that involve all societal groups by engaging them in constructive dialogue.

Keywords: bio-based economy; citizens; consumer behaviour; online survey; society; transformation



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1. Introduction

Transitioning to a bioeconomy by substituting fossil resources with renewable resources is widely held to be a necessary way to achieve the UN's Sustainable Development Goals, including reducing the rate of global warming [1–3]. The European Commission has defined bioeconomy as "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" [4] (p. 6). Other established definitions of a bioeconomy include the explicit aim of substituting fossil resources with renewable resources [5,6].

This proposed transition has been the subject of significant and growing attention over the past decade, not only among scholars but also in politics, business, and the media. This interest is reflected in the numerous bioeconomy strategy papers published worldwide, e.g., [4,7], as well as in scientific publications and the popular media [2]. One of the main streams of research on the bioeconomy is focused primarily on developing technological solutions such as bio-technical innovations and applications to achieve this transition, including the large-scale development of bio-based products [8,9]. Another research stream is focused on the consumption-related aspects of achieving this transition. For example,

researchers in this stream have conducted studies to identify consumer perceptions and levels of acceptance of various bio-based products, e.g., [10–13]. These studies and their findings reflect the relevance of consumers and markets in the acceptance of bioeconomy-related technological developments and technology transfer [14].

Transitioning to a bio-based economy inevitably entails a wide range of substantial adaptations in current modes of production, processing, and consumption. In addition to the substitution of fossil resources by biomass and the introduction of new technologies, these adaptations include the development of a circular economy, “cascade use”, and major changes and significant reductions in consumption, possibly even necessitating a new understanding of the meaning of economic “growth” [15]. Given the impacts these changes will have on so many aspects of our everyday lives, any analysis of the challenges and consequences of transitioning to a bioeconomy requires researchers to apply a holistic approach that gives a voice not only to civil society stakeholders but to all groups in society [9,16–19].

Key concerns raised in discussions about the transition to a bioeconomy include issues related to the increased demand and competition for biogenic resources that such a transition entails [18,19]. Potential barriers to public acceptance of this transition thus encompass fears about the future availability and distribution of biogenic resources for different uses, concomitant changes in land-use and potential over-exploitation of natural resources, including major concerns about food security, as expressed in the so-called “food versus fuel” debate [3,7,20]. The envisaged competition for scarce biogenic resources has led to calls for far-reaching “technological innovations, production chain adjustments, policy change and emerging public support” [11] (p. 130) as prerequisites for successfully transitioning to a bio-based economy.

The wide-ranging impacts on people’s everyday lives of implementing these changes include major changes in transport and mobility, diet, and consumption [21,22]. Identifying and analyzing public attitudes to these impacts is not only necessary but is also highly complex. For example, while it is well understood that levels of meat and dairy consumption are significant factors in any transition to a sustainable food system, ethical discussions on the sustainable share of meat in our diets and the associated debate on “efficiency versus sufficiency” tend to be highly emotional, reflecting the fundamental role that consumption is seen to play in prevailing perceptions of individual wellbeing [23–25]. And while the negative environmental effects of current consumption levels might be partly offset by technical innovations and increased efficiency in production, processing and consumption, the adoption of these innovations might also be associated with negative social and environmental consequences [5,15,19,26].

Recognizing the scale and extent of these impacts on all members of civil society, it is self-evident that transitioning to a bio-based economy will require widespread acceptance and support among citizens [2,21,25,27,28]. Addressing these key social and ethical dimensions of the proposed transition will thus be critical for the success of this transformation. For this reason, gaining knowledge and understanding of societal perceptions and addressing these attitudes and concerns by engaging in societal dialog must thus be an integral part of any efforts to support the transformation to a bio-based economy [21,29,30]. This need to gauge and understand the attitudes and responses of different societal groups to the technological and economic changes associated with the transition to a bioeconomy has been widely recognized by scholars [16,18,31,32], and there is a growing consensus that achieving this transition will depend to a large degree on whether and to what extent society as a whole can be actively engaged and involved in supporting this transformation process [5,33].

With this study, we add to existing research on societal perceptions of the proposed transition by assessing and analyzing the attitudes of German citizens towards the possible consequences of shifting to a bio-based economy and associated bioeconomic developments. For this purpose, we developed three different future scenarios modelling the impacts on people’s everyday lives of replacing fossil resources with biogenic resources in Germany

by 2050, with each scenario based on different levels of resource replacement. We then conducted an online survey asking people to evaluate the scenarios. In analyzing the collected data, we took account of the participants' evaluations of each scenario as a whole, identifying the factors that appeared to be most influential in determining their levels and the participants' evaluations of the scenarios. Based on our findings, we elaborate key recommendations for using targeted communications both to inform people of the challenges and benefits of transitioning to a bio-based economy and to address public concerns about the consequences of this transition.

In the following section, we provide a description of the three bioeconomy scenarios. We then describe the sample of the online survey and the questionnaire in the Methods section before presenting the participants' evaluations of the three scenarios in the Results section, including their main concerns and our findings regarding the key predictors of higher or lower levels of acceptance. We close with the Conclusions section with recommendations as to how communications can more effectively engage citizens and gain a greater public acceptance of the transformations entailed in the transition to a bioeconomy.

2. Three Bioeconomy Scenarios

As depictions of possible future situations as well as of the paths that might lead to these situations [34], scenarios are helpful tools for identifying and conveying the future development pathways of technologies and their consequences [18,19,27]. As such, scenarios serve as a means to estimate the effects of decisions and different influencing variables and to better understand and communicate the complexities and uncertainties of systemic changes [18,19,35]. Recently, scenario techniques have been used to show different and future situations of the bioeconomy and sustainable development [18,19,36].

Our rationale for constructing scenarios of the transition to a bio-based economy in Germany for this study is based both on the need for effective tools to communicate research findings and assumptions to an interested public and the equally pressing need to involve and gain the support of the wider public in this process of transition, including actively engaging interested citizens in the design of this process.

The three scenarios we employed in our study were carefully developed in a participatory process through stepwise cooperation between scientists and a panel of stakeholders, together resulting in scenarios that included both qualitative and quantitative elements. The elements of these scenarios describe various possible future development paths of the German bioeconomy, representing the shared views and predictions of different stakeholders and scientists. In repeated rounds of discussions with stakeholder groups, it was ensured that the developed scenarios were equally relevant and consistent for decision-makers, scientists, planners, and practitioners alike. The whole process of developing the scenarios thus further served as a communicative bridge between scientists and various interest groups, providing them with a valuable opportunity to combine their extensive combined knowledge of social, technological, and economic developments.

Three very different scenarios for Germany in the year 2050 were developed in this way, varying according to the extent of transition each scenario envisaged and the consequences of the respective degrees of integration of bio-based economic activities. Thus: the first scenario, "Bioeconomy on the Drip", depicts the lowest level of transition towards a bioeconomy and the least changes to people's current lives; the second scenario, "Bioeconomy Islands", represents a resource-intense bioeconomy with intensified socio-economic polarization; and the third scenario, "Bioeconomy Change", shows the highest degree of transition with major short-term adaptations but greater socio-economic unity in the long term (see also [37]).

2.1. Scenario One: "Bioeconomy on the Drip"—An Expansive Economy with Marginal Use of Bio-Based Resources and Processes

In the "Bioeconomy on the Drip" scenario, climate action and environmental protection remain a relatively low priority in society and politics in 2050. Although the consequences

of climate change are widely acknowledged in Germany, no fundamental changes have been made to the current ways of consuming and doing business. Other problems are generally perceived as significantly more urgent than the need for sustainable development and climate action; and this low prioritization of environmental challenges is reflected and perpetuated in political priorities. In this scenario, there is little explicit and effective promotion of the benefits of adopting bioeconomic technologies and processes, which in turn negatively affect investment activities in the bio-based economy, with only individual niche products entering the market. Bio-based products are not widely accepted by the general public, mostly because mineral oil-based products are perceived to be more cost-effective. In combination with a lack of public funding, these factors mean that there is little incentive to develop new bio-based products and hence little or no strategic focus in the industrial sector on establishing a bioeconomy.

Widespread indifference to the need for climate action, sustainable development, and protection of the environment in general means that people in Germany in 2050 are barely aware of the advantages of using renewable resources for mitigating the harmful effects of production and consumption on the environment, as is reflected and perpetuated by a lack of incentives for environmental protection, such as the expansion of conservation areas.

Energy demands are largely covered by fossil fuels—oil and gas—extracted from conventional sources and through the increased use of less traditional techniques such as fracking. Indeed, in this scenario, the demand for energy based on fossil resources is increasing in the transport sector, especially for road and air transport. Few if any affordable renewable sources of energy have been developed; moreover, all of them have led to ever-increasing CO₂ emissions.

International trade is characterized by conflict, with primarily national interests being pursued, including the imposition of tariff barriers to protect domestic production. Globally, there is insufficient regulation of land use, with many countries increasing deforestation by 2030, mostly for the expansion of agriculture. This trend will be only partially offset by reforestation in Europe and China in subsequent years.

2.2. Scenario Two: “Bioeconomy Islands”—Resource-Intense Bioeconomy in a Polarized World

In this scenario there is greater and increasing sensibility on the part of the German population to the consequences of climate change. A rise in per capita income and prosperity helps to foster this growing environmental awareness in society; and by 2050 there is a strong and growing demand for bio-based products among more affluent sections of the population, albeit that the high prices of these sustainable products render them inaccessible for most people from other socio-economic classes. As a consequence of this socio-economic disparity, there is heated and intensifying debate about the merits and social costs of sustainable but expensive production versus the production of goods affordable for everyone.

Although state subsidies are reduced for industries that cause the greatest environmental depletion in this scenario, there are otherwise few significant political or state-driven initiatives aimed at developing a bio-based economy or in support of integrating bio-economic adaptations in existing economic structures. Most developmental efforts and progress to support transition to a bioeconomy are initiated by industry rather than by the state, primarily in response to market signals from consumers. In combination with high prices for bio-based products, this lack of political intervention leads to an increased stratification of civil society, with only those sectors and actors directly involved in bioeconomy-related measures and processes gaining any significant profit from such innovations.

In this second scenario, international trade barriers are relatively relaxed, facilitating largely barrier-free international trade in agricultural commodities. The main beneficiaries of such liberalization are industrial countries; however, low-income countries continue to lack access to Western middle and high-income markets. The increased use of renewable resources in Germany has significant adverse consequences for exporting and/or developing countries. These consequences arise from transferring the negative environmental effects

of production to these countries and unfair trading conditions related to the import of renewable resources, thereby perpetuating and exacerbating the socio-economic disparity between developing and industrialized countries.

Energy consumption in Germany has decreased slightly by 2050, with an increasing proportion of energy demand covered by renewable energy sources, including biomass. The share of biomass in the total input into the chemical sectors is also increasing. A large proportion of biomass required for material and energetic use in Germany continues to be imported. Emissions from the combustion of fossil fuels have been significantly reduced as a result of substantial progress in the electrification of the transport sector.

Due to the significant increase in domestic demand for biomass, land use in Germany is mainly based on the principle of “functional protection”, meaning that land use must be sustainable. Reforestation efforts in Europe and China lead to a small increase in global forest area by 2050.

2.3. Scenario Three: “Bioeconomy Change”—A Circular Bioeconomy in a United World

In this third scenario, a young generation educated in and highly aware of the need for sustainability is emerging in Germany in 2050 in rapidly changing environmental and climatic conditions. This generation demands reforms oriented towards a sustainable and equitable world order. Increasing per capita income and prosperity in German society has further facilitated greater societal awareness and prioritization of environmental and climate change. Although the “food versus fuel” debate initially intensified, this discourse is more subdued by 2050 with the introduction and dissemination of innovative resource-saving technologies. Policymakers are facilitating and promoting a holistic transformation towards a circular bio-based economy through the consistent use of incentives such as subsidies and taxes, in combination with effective regulatory mechanisms. A tax on consumer goods based on their ecological footprint increases prices for resource-intensive products and services, including food, is helping to pave the way towards sustainable consumption. Reduced consumption and sufficiency are further effects of this policy. Social hardships caused by rising consumer prices are offset by appropriate compensation mechanisms, including a redistribution of wealth by means of tax schemes.

The rapid transformation envisaged in this “Bioeconomy Change” scenario is also driven by major advances in technology. These technological leaps include new technologies for energy production and biomass-processing, as well as new farming systems and breeding methods that enable the decoupling of biomass production from land use. At the same time, the industrial production of raw materials with the use of microorganisms, especially in the chemical sector, significantly reduces the demand for biomass from agriculture and forestry in both energy and material use, enabling the release of formerly productive land area. Domestic production can now mostly meet the reduced demand for biomass. Innovative solutions in the food sector include in-vitro meat synthesis to replace the need for conventional meat production and the synthesis of chemicals on the basis of artificial photosynthesis, as well as carbon sequestration. Pressure on land and competition between various forms of resource usage is thus markedly reduced.

By 2050, international trade is largely barrier-free, facilitating the global exchange of technology, capital, and know-how. This in turn empowers developing nations to align themselves economically with industrial nations without generating or incurring negative environmental impacts.

Energy consumption per year is rapidly decreasing in Germany and a very large proportion of energy demand is now covered by renewable energy sources. The demand for fuels in the transport sector has declined considerably due to significant expansion and subsidization of the country’s local and regional public transport systems. Overall, these adaptations have led to a major reduction in Germany’s total GHG emissions by 2050.

Strong global regulation of land use, in addition to major reforestation and forest regeneration efforts, combined with the global adoption of European environmental policies contributes to a significant reduction in the rates of global deforestation. Ultimately, global

deforestation will be stopped altogether in this scenario, meaning forest land worldwide will increase significantly due to regrowth in areas relieved of the burden of production.

The consistent and comprehensive promotion of organic farming by politicians has led to a comprehensive “greening” of agriculture by 2050 in the “Bioeconomy Change” scenario. This includes a significant reduction in the use of pesticides and fertilizers, leading to a significant improvement in the condition of both anthropogenic and natural ecosystems.

3. Materials and Methods

A standardized online survey was conducted in Germany in November 2019 to gather data on citizens’ perceptions and evaluations of the acceptability of the three bioeconomy scenarios outlined above. The sample of 1473 participants was representative of the German population for the 18–75 age group in terms of age, gender, formal education, and income (Table 1). The data collection was outsourced to a private market research agency, while the responsibility for designing the questionnaire and for the analysis of the data lies with the authors.

Table 1. Sample description and comparison with the German average (in %).

	Sample (N = 1473)	Germany (18–75 Years of Age)
Gender		
Female	46	51
Male	54	49
Age in years		
18–29	16	19
30–39	22	18
40–49	22	18
50–59	30	22
60–75	10	23
Formal education		
No formal education	1	6
9 or 10 years of education	60	60
12 to 13 years of education	40	33

Source: [38].

The questionnaire consisted of four different sections. In the first section, the participants were asked about their overall satisfaction with their personal lives. The second section comprised questions eliciting the respondents’ perceptions and assessments of the three bioeconomy scenarios. A key challenge we faced in designing this section was how to present the rather complex scenarios in such a way as to enable the participants to make informed individual assessments in their position as “bioeconomy laypeople”. To this end, we broke the scenarios down into several distinct economic and social elements. These elements were then visualized using graphical representations the participants could click to open pop-up windows with informational text corresponding to the selected topic (See Figure 1, as well as the Appendix A containing the text provided in the pop-up windows.).

In this way, the participants were able to decide on their specific demand for information and to explore the contents of the scenarios in an interactive manner. Since all three scenarios were rather complex, we decided to present each participant with only two scenarios. For this aim, three subsamples of participants were created with identical structures, each subsample assessing two scenarios. This resulted in approximately 1000 evaluations for each of the three scenarios.

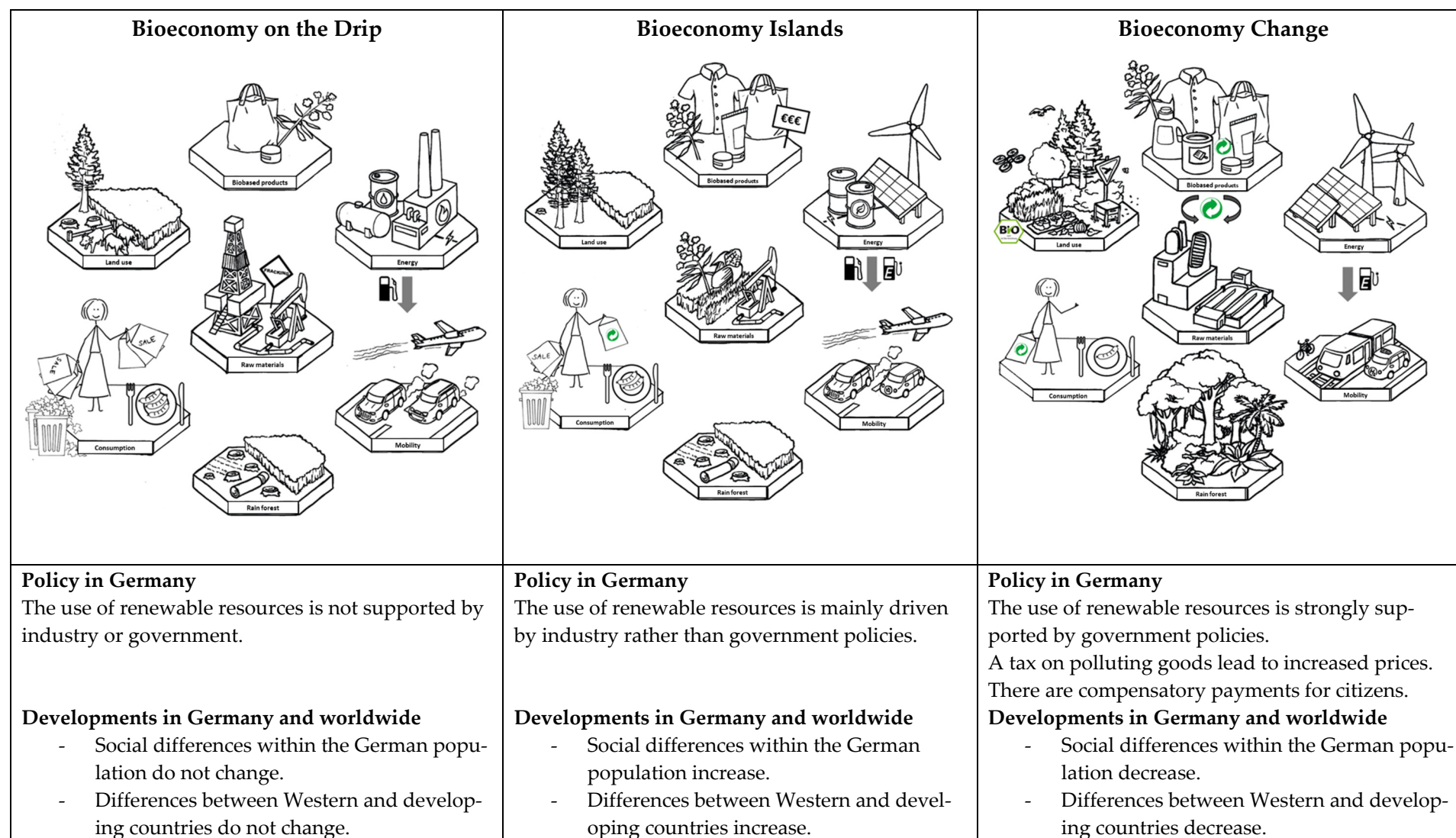


Figure 1. The three bioeconomy scenarios as presented to the survey participants.

The third section of the questionnaire elicited the participants' assessments of the scenarios through the following three questions: (a) an open question on their likes and dislikes regarding each scenario; (b) a rating task to elicit their evaluations of the scenarios according to different indicators; and (c) questions about the changes the respondents anticipated in terms of their individual levels of life satisfaction if the respective scenarios were to become reality.

Since all three scenarios were rather abstract, the respondents were given the opportunity to indicate the elements of the scenarios they liked or disliked in an open-ended manner. This also enabled us to gain a better understanding of the participants' opinions about specific elements in the scenarios. The answers (verbatim) were coded by means of quantitative content analysis. As a further indicator, the respondents were asked to assess the liking of each scenario on a scale from 1 = "I don't like it at all" to 6 = "I love it".

Levels of acceptance depend on attitudes that are shaped by cognitive, affective, and conative criteria. Cognitive criteria are assessments developed on the basis of knowledge and ideas, while affective criteria refer to emotional expressions about the scenarios, and conative criteria refer to latent readiness to act according to attitudes [36]. The study participants were asked to evaluate the three scenarios according to these criteria as shown in Table 2 below.

Table 2. Attitude-shaping components.

Components of Attitudes	Criteria	
Conative	not desirable to be rejected	desirable worth supporting
Affective	annoying frightening unnecessary backward	pleasing calming necessary progressive
Cognitive	antisocial endangers jobs limiting expensive	social creates jobs liberal cheap

Source: Adapted from [39].

From the point of view of individual citizens, scenarios can be assessed according to how these possible futures are expected to affect their own lives. Since overall individual "life satisfaction" is a key part of subjective wellbeing and an important driver of acceptance [40], we used this as an additional indicator for measuring the likely acceptance of the presented scenarios. At the beginning of the survey, the participants were asked to indicate their overall satisfaction with life in general on a six-point Likert scale (1 = "not at all satisfied" to 6 = "completely satisfied"). Later, after having been presented with the scenarios, the participants were asked to indicate the level of life satisfaction they expected in the future scenarios, thereby providing the opportunity to compare the respondent's answers to both these questions.

In the fourth section, the participants' attitudes to a bio-based economy were elicited together with their assessments of various measures for ensuring a sustainable future. Given the major impact of attitudes on the respondents' evaluations of the three scenarios, we measured the participants' attitudes towards a number of key aspects of a bio-based economy by asking them to indicate their level of agreement or disagreement with ten bioeconomic aspects on a six-point Likert scale from "strongly disagree" to "strongly agree". (The ten items were adapted from [41], who conducted a quantitative survey on citizens' perception of the bioeconomy.) The participants' responses to these statements were later condensed into three factors by means of a principal component analysis. As a final task of the questionnaire, the respondents were asked to provide sociodemographic information.

With the aim of better understanding the respondents' assessments and degrees of liking for the three scenarios, a linear regression analysis was calculated with the dependent

variable being their degree of “liking” of each of the three scenarios (from 1 = “I don’t like it at all” to 6 = “I love it”). Socio-demographics, attitudes, and overall levels of expected satisfaction in each of the scenarios were used as explanatory variables.

4. Results

This results section starts with a quantitative content analysis of the open question on the respondents’ likes and dislikes of the scenarios. This is followed by our analysis of the respondents’ general evaluation of the bioeconomy scenarios, making use of the indicator changes in their levels of “satisfaction with life”. Finally, we identify the individual driving factors behind the participants’ evaluations of each of the scenarios.

4.1. Likes and Dislikes of the Three Scenarios

While the vast majority of the participants indicated positive aspects of the “Bioeconomy Change” scenario, this share was much lower for the other two scenarios involving fewer adaptations to a bioeconomy. Almost 80% of respondents expressed negative assessments of both the “Bioeconomy on the drip” and “Bioeconomy Islands” scenarios, while only 39% assessed the “Bioeconomy Change” scenario negatively. Table 3 presents the most frequently mentioned likes (positive aspects) and dislikes (negative aspects) of the scenarios.

Table 3. Positive and negative aspects of the scenarios ¹.

	Bioeconomy on the Drip (n = 968)	Bioeconomy Islands (n = 995)	Bioeconomy Change (n = 983)
Positive aspects	25% Stagnation, “everything remains the same” Social inequality in Germany does not increase	50% Energy use Positive environmental effects Use of renewable resources	80% Positive environmental effects Social inequality in Germany declines Active role of policy
Negative aspects	79% Negative environmental effects Intensified climate change Passive role of policy Stagnation, “everything remains the same” Consumption-oriented lifestyle	78% Social inequality in Germany increases Change of land use in export countries Mobility Consumption-oriented lifestyle	39% Increased consumer prices Active role of policy

¹ Open question: “What do you like (not like) about this scenario?”.

The respondents mainly attributed negative environmental effects to the “Bioeconomy on the Drip” scenario. The dislikes most frequently expressed with regard to this scenario were thus the negative impacts on the environment and the fact that climate change would not be effectively addressed in this scenario. The participants primarily perceived consumption-oriented lifestyles as environmentally harmful, since such lifestyles lead to large-scale waste of energy and massive depletion of natural resources. In their view, such lifestyles are fueled primarily by profit-maximising business strategies and a lack of political regulation. The scenario as a whole was accordingly assessed as unsustainable.

Of course, I do not like the way resources are handled and the fact that nothing is done by politicians. This means that no one really cares about the problems of the country or that politicians do not make people change their minds. (ID 2881) (Italicized text indicates quotations from the participants’ responses when asked to state their likes and dislikes.)

The respondents also identified more negative than positive aspects in the “Bioeconomy Islands” scenario. One of the most frequently mentioned disadvantages of this scenario was the increasing inequality it implied for German society in terms of income disparities, with societal polarization between a fraction of the population able to afford expensive

bio-based products and a majority unable or unwilling to raise the necessary financial resources for these products. This degree of social inequality was deemed unacceptable by the majority of respondents.

Many participants also criticized the use of renewable resources in Germany at the expense of exporting and/or developing countries envisaged in this scenario, whether this global disparity resulted from shifting the negative environmental effects of production to these countries or because of unfair terms of trade when importing renewable resources to Germany, all of which serves to perpetuate and exacerbate economic and social differences between developing and industrialized countries.

We virtually exploit other countries in order to realise our lifestyle. And we lie to ourselves about a clean environment. But climate change does not stop at the border. (ID 3148)

Another aspect of this second scenario that many respondents considered negative was the form of mobility envisaged in this scenario. In addition to their criticisms of air traffic, the respondents also did not generally recognize electric cars as constituting a more sustainable alternative to the combustion engine. In their view, the goal of better environmental compatibility would be more effectively achieved through limitations on air traffic.

Although some 80% of the respondents identified specific negative aspects of the “Bioeconomy Islands” scenario, about half assessed this scenario positively overall. The main reason for this positive assessment was that energy demand in Germany would mostly be covered by renewable energy sources in this scenario.

Renewable energies—Because of climate change, we need an alternative to fossil energy sources today and renewable energy sources are the best alternative. (ID 4392)

In general, this second scenario was described by respondents as environmentally friendlier than the first scenario, since it would involve sustainable approaches with less harmful environmental impacts. The respondents appreciated that more attention would be paid to the environment in this scenario both in individual lifestyles and the supply of raw materials for industry. The participants thus rated the use of renewable raw materials positively, especially for bio-based products. The depicted increase in European forest areas was explicitly endorsed.

The “Bioeconomy Change” scenario was assessed as sustainable by the respondents, who attributed it with more positive than negative aspects. In this vision of the future, harmful environmental influences by humans at the national and global level would be reduced to a minimum and climate change would be mitigated, all of which was associated with positive effects on people’s quality of life, especially in terms of well-being and health. Sustainable lifestyles with conscientious consumer behavior were also seen as positive and were understood as part of leading a “good life”. The reduction of socio-economic disparities and the convergence of social groups both within Germany and at the global level was seen as another major advantage of the scenario in combining sustainability with social harmonization.

... that sustainability is promoted in such a way that social hardships are compensated and avoided, both nationally and internationally, and that our ecological success is neither achieved at the expense of developing countries nor leads to further redistribution from the bottom to the top. Furthermore, I believe that governmental steering through taxes is indispensable to trigger environmental change and social compensation. (ID 2950)

With regard to the role of politics and policies in the “Bioeconomy Change” scenario, there was no clear consensus from the study participants. Nevertheless, an active role of the state in shaping the “Bioeconomy Change” scenario was assessed very positively, being also considered a prerequisite for the development of sustainable structures in all areas of life. Most participants welcomed the state’s role and willingness to shape the future in general, including through the imposition of a consumer goods tax based on the ecological footprint of products and a compensation mechanism for low-income population groups. However,

the additional tax burden on citizens did raise concerns, and some participants queried the effectiveness of reimbursement and compensation schemes. The most frequently mentioned disadvantage of this scenario was the fear that life would generally become more expensive, with a concomitant loss of wellbeing.

That everything will become more expensive, less comfortable and above all poorer. I do not want Germany's prosperity to fall. (ID 2596)

4.2. Attitudes towards the Three Scenarios

As explained in the methods section above, the study participants were asked to evaluate the three scenarios according to conative, cognitive, and affective criteria; the results are presented in the form of semantic differential (Figure 2). While the respondents' attitudes towards the "Bioeconomy on the Drip" and the "Bioeconomy Islands" scenarios were quite similar, their attitudes towards the "Bioeconomy Change" scenario differed markedly. As shown in Figure 2, the "Bioeconomy on the Drip" scenario was predominantly perceived negatively, with the mean values all found to the left of the central line (Figure 2). According to the responses, this scenario was not only rather "backward" and "antisocial" but even had a "frightening" effect.

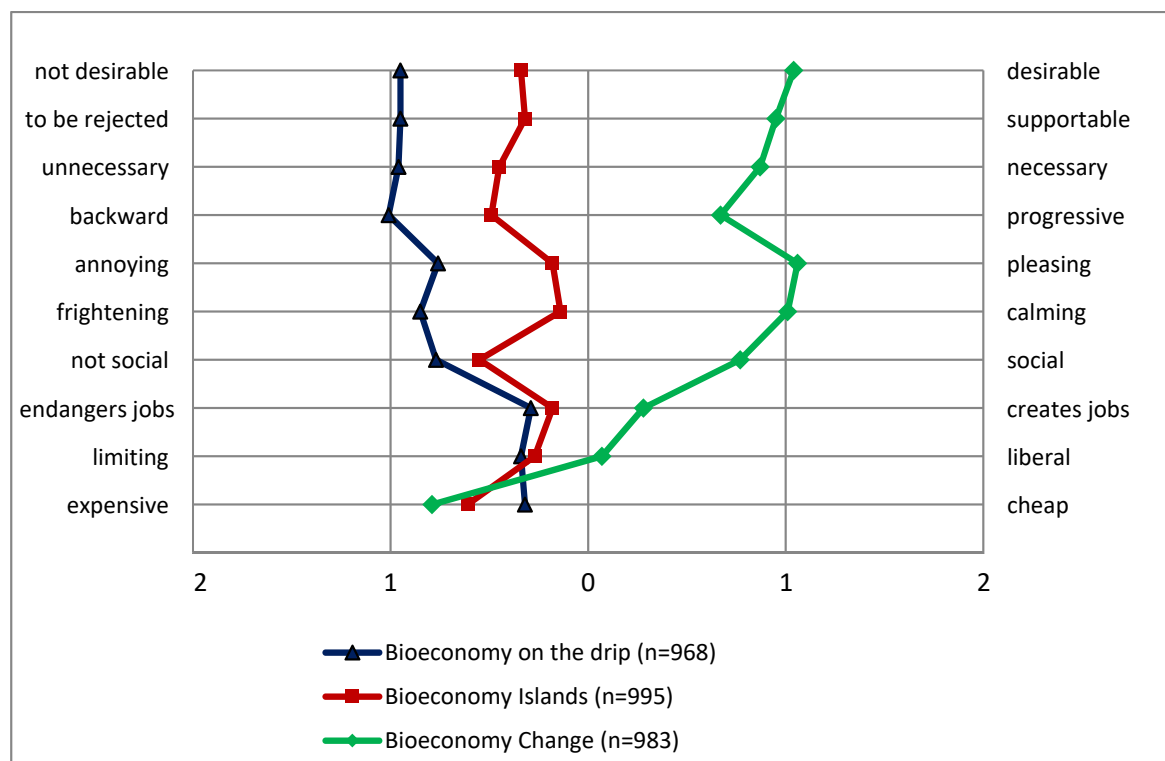


Figure 2. Attitudes towards the three scenarios based on determining criteria (semantic differential) *.
* Participants were asked to indicate their evaluation between the two poles.

The "Bioeconomy Islands" scenario was also rated very low in all evaluation dimensions of the semantic differential. Likewise, this scenario was also perceived as being "antisocial" and rather "annoying" for the study participants. In the case of the "Bioeconomy Change" scenario, the respondents show positive attitudes reflected in almost all the evaluation dimensions, with the mean values all to the right of the central line with the exception of the "expensive—cheap" attribute pair (Figure 2). The perceived positive characteristics of this scenario seem to outweigh, for the participants, the negative effects of products being more "expensive".

The greatest differences in the respondents' evaluations of the three scenarios are found in the criteria "not desirable—desirable" and "to be rejected—worth supporting". From

the participants' perspectives, the "Bioeconomy Change" scenario was clearly adjudged as being more desirable and supportable than the other two visions of the future.

4.3. General Evaluation of the Three Scenarios

In order to get an idea of how the respondents perceived the likely impacts of each of the scenarios on their levels of life satisfaction, we asked them to state their current levels of life satisfaction before presenting the different scenarios and then later asked them again to indicate what this level would be in relation to the different scenarios (Figure 3). The average stated level of overall life satisfaction in the present was 4.14. In the "Bioeconomy on the drip" scenario, almost half of the respondents assumed that their satisfaction would drop, with an average value of 2.60. Only in the "Bioeconomy Change" scenario did this overall level increase above the present levels, rising to 4.32. This indicates that going ahead with "business as usual", as is approximately the case depicted in the "Bioeconomy on the drip" scenario, will severely reduce people's overall satisfaction with life in Germany over the coming decades. Significant changes to the economy and a major re-orientation towards a bio-based economy will be needed, therefore, even to maintain people's current overall satisfaction with life.

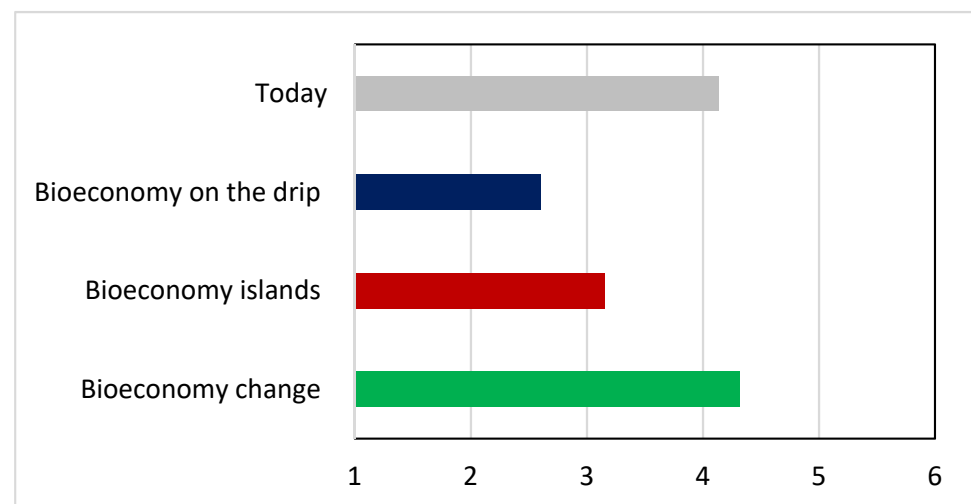


Figure 3. Expected changes in overall life satisfaction in the three scenarios (in %)*. * 1—"not at all satisfied" to 6—"completely satisfied".

4.4. Explaining the Liking of the Different Scenarios

A further indicator used to assess the respondents' attitudes and overall evaluations of the three scenarios was that of "liking", assessed on a scale from 1 = "I don't like it at all" to 6 = "I love it". The average liking among the participants for the "Bioeconomy on the drip" scenario was low, at 2.31, slightly higher for "Bioeconomy Islands" at 2.96, and highest for "Bioeconomy Change", which was rated on average at 4.48.

To better ascertain the driving factors behind these levels of liking and disliking of the three scenarios and their degree of acceptance by the respondents, a linear regression model was calculated in which the explanatory variables comprised socio-demographics, overall levels of satisfaction with life, and general attitudes towards the bioeconomy. As explained above, these attitudes were elicited using a total of ten items. By means of a principal component analysis, these attitudinal items were reduced to three factors (Table 4). Cronbach's alpha was good for all factors.

Table 4. Factor loadings of items for attitudes towards different aspects of bio-economic development.

Item	Factor Loadings
Environment focus (Cronbach's alpha = 0.724)	
In view of climate change, resource scarcity and environmental problems, we can no longer carry on as before. We have to say goodbye to economic growth and learn to be happy even with less.	0.810
Something important has been lost in many people, namely to see themselves as part of the environment again and to learn to understand natural connections.	0.791
With bio-based economy we can reduce the huge dependence on oil, but we have to rely on more and more efficient technologies because of the growing demand for biomass.	0.688
To phase out fossil fuels, we simply need to save more energy instead of relying only on renewable resources.	0.628
Economy focus (Cronbach's alpha = 0.632)	
The conversion of industry to renewable raw materials must not burden the economy.	0.778
There is dramatization when talking about the finite nature of fossil resources.	0.694
I believe most of the future environmental problems will be solved by technological progress.	0.538
Technological progress will increase the life quality of future generations.	0.527
Technology focus (Cronbach's alpha = 0.667)	
Modifying genes for industrial purposes is fine.	0.852
It is a fact that genetically modified food is becoming more and more necessary to feed the growing world population.	0.832

Share of variance explained: 59.65%. KMO: 0.728; Principal component analysis, varimax rotation.

According to the items loaded onto each factor, the three factors were entitled “Environment focus”, “Economy focus” and “Technology focus”. The first factor, “Environment focus”, refers to the respondents’ recognition of the necessity of reducing consumption, including the need for material sacrifices for the sake of sustainable future development. From this “focus”, humans are perceived to be part of nature and thus it is ourselves who should adapt to natural conditions and not the other way around. Those holding this attitude strongly questioned the sustainability and ethics of an economy oriented solely towards growth. The second factor, “Economy focus”, represents an economy-oriented perspective which embraces that the economy and economic growth must not be obstructed. This attitude is consistent with the view that the overall situation at present is not alarming and that technological progress will solve most problems. The third factor, “Technology focus”, places still greater emphasis on the role of new technologies in solving environmental, socio-economic, and even ethical problems, including hunger and poverty, with genetic modification serving as a proxy for this perspective.

The results of the linear regression analysis show that the differences in the respondents’ evaluation of the scenarios can be explained to a fair extent by the selected indicators (Table 5). Attitudinal factors had a stronger influence on liking than sociodemographic factors such as gender, age and education. Our comparative analysis of the three regression analyses show that attitudinal factors largely have opposite effects on the respondents’ assessments of the two extreme scenarios, “Bioeconomy on the Drip” and “Bioeconomy Change”. A higher environmental orientation (“Environment focus”) has a significant positive effect on degrees of liking for the “Bioeconomy Change” scenario and a significant negative effect on liking for the “Bioeconomy on the Drip” scenario. However, when great importance is attached to the economic viability of the bioeconomy (i.e., “Economy focus”), then the two scenarios of “Bioeconomy on the Drip” and “Bioeconomy Islands” are significantly more liked, whereas this factor exerts a negative influence on liking for the “Bioeconomy Change” scenario. A “Technology focus” positively affected respondents’ levels of liking for all three scenarios, albeit to different degrees.

Table 5. Effects of different personal indicators on the respondents' liking of the three scenarios (linear regression analysis, beta coefficients).

Dependent Variable: Liking of each Scenario ^a	Bioeconomy on the Drip	Bioeconomy Islands	Bioeconomy Change
Constant term	***	***	***
Women ^b	0.000	0.041	0.046 *
Age	0.065 **	−0.062 **	−0.085 ***
Education ^c	−0.052 *	−0.064 **	0.033
Overall satisfaction with life	0.065 **	0.216 ***	0.183 ***
Attitude towards bioeconomy			
Environment focus	−0.268 ***	0.012	0.565 ***
Economy focus	0.337 ***	0.190 ***	−0.157 ***
Technology focus	0.198 ***	0.188 ***	0.043 *
Goodness of fit			
F-value	45.94 ***	23.60 ***	105.87 ***
R ²	0.492	0.371	0.647
Corr. R ²	0.236	0.138	0.419
n	1016	1042	1035

^a Question: How do you like this scenario for Germany overall? Answer based on a Likert scale from 1 = "I don't like it at all" to 6 = "I love it". ^b Dummy variable: 1 = female; 0 = male. ^c 7 values from 0 = no final education, to 6 = higher education. * - $p = 0.1$, ** - $p = 0.05$, *** $p = 0.01$.

As shown in Table 5, the female respondents evinced a significantly higher liking for the "Bioeconomy Change" scenario. Older respondents more often favoured the "Bioeconomy on the drip" scenario, while younger people preferred the two other scenarios entailing more adaptation to a bio-based economy. Lower education is associated with greater levels of liking for the "Bioeconomy on the drip" and "Bioeconomy Islands" scenarios. Interestingly, higher levels of overall life satisfaction are associated with greater liking for all three scenarios.

5. Discussion

This study has surveyed and analysed public perceptions in Germany of the transition to a bioeconomy and levels of public acceptance of the wide-ranging societal consequences of this transformation. The current attitudes of the German population towards the changes involved in this transition were elicited by presenting study participants with different possible scenarios outlining the consequences of different degrees of adaptation: (i) "Bioeconomy on the Drip"; (ii) "Bioeconomy Islands"; and (iii) "Bioeconomy Change".

Of these scenarios, "Bioeconomy Change" most closely resembles the scale of transformation considered essential to achieve a bio-based economy and to solve major environmental and social problems at a global level.

The rationale behind calls for governments to commit to the transition to a bio-based economy has been widely and repeatedly stated in terms of the need to tackle global warming, the increasing scarcity of fossil resources, and the need to feed the world's growing population [2,3]. However, the effective implementation of measures to ensure this transition will depend in large part on the degree to which they are accepted by the population. This need for public acceptance is further supported by the conclusion of a recent inter- and transdisciplinary research project [18], which emphasizes that transitioning to a bioeconomy will affect all members of society, making it crucial to consider and integrate the views and wishes of citizens regarding this process in order to increase levels of acceptability for specific measures.

From the current viewpoint of the German public, as reflected in the attitudes of the participants of this study and their evaluations of the three scenarios, the main disadvantages of transitioning to a bioeconomy relate to negative socio-economic effects, including price increases and the exacerbation of social injustices. For example, the large-scale substitution of fossil raw materials by renewables was widely associated by the participants with fears that life would become more expensive and that living standards would decline.

As [19] pointed out, these fears are not unrealistic, especially given the risk that focusing political support on promoting a single specific bioeconomic niche such as biofuels may lead to the almost total absorption of available biomass resources, thereby hampering the development of other crucial niches. Given the likelihood of this intensified competition for biomass resources, therefore, we can assume a future scarcity of biomass resources in other sectors and, as a result, rising prices for, e.g., products of the chemical bioeconomy sector.

Our research confirms that attitudes towards the bioeconomy and public acceptance of the potential consequences of this transition vary significantly between different population groups. These differences also relate to emotional factors, further confirming the findings of previous research [31]. From their respective likings of the three scenarios, we can usefully distinguish two main groups among the study participants: (i) citizens with a strong focus on the economic aspects of the proposed transition preferring the “Bioeconomy on the drip” scenario or the “Bioeconomy Island” scenario; and (ii) citizens with a strong focus on the environment, which leads to a preference of the “Bioeconomy Change” scenario. The findings thus expand on the contradictions and concerns identified by previous studies in public attitudes towards ecological and socio-economic values and goals [42].

6. Conclusions

The results of our analysis indicate that most German citizens see the need for major socio-economic change towards a bio-based economy to ensure a sustainable future, above all through the substitution of fossil resources for bio-based raw materials. However, people will also need to be willing to change their consumption patterns, including a reduction in current consumption levels and acceptance will need to be gained for higher prices for bio-based products and higher taxes on conventional products.

The successful future expansion of the bioeconomy is thus linked to certain framework conditions, above all in the need for politics to play an active role, including providing incentives for the industrial use of renewable raw materials and promoting sustainable consumption decisions through the imposition of taxes. To avoid the burden of these changes falling disproportionately on the socio-economically vulnerable, any tax on non-renewable resources will need to be aligned with functioning compensation mechanisms. This conclusion is in line with [19] who have highlighted the crucial role of policy in the process of holistic transformation to a bio-based economy, including by specific public support niches aimed at increasing the price competitiveness of bio-based products and thus promoting their adoption under current market conditions.

As our survey further shows, most German citizens regard an environment with low social disparities as fundamental for a successful societal transformation towards a bioeconomy or bio-based economy. This applies not only to inequalities and disparities in social structures within Germany but also to differences between industrialized and developing countries. These concerns will need to be taken seriously by policymakers in order to accomplish the transition to a bio-based economy with as little social conflict as possible.

Political interventions in favour of the transition to a bioeconomy must be accompanied by well-designed and targeted communications in order to make the necessity and objectives of these interventions comprehensible to the population. There is a wide consensus among scientists that citizens need to be engaged in developing and putting into force any such transformation toward a bio-based economy, e.g., [5,31].

Involving citizens in the drafting of actions to bring about this transformation is highly challenging, since attitudes, perceptions, emotions, and needs vary greatly among different groups of the population. As our results have shown, the older people in our survey seemed particularly skeptical about the two more radical bioeconomy scenarios and the significant changes these imply as compared with the status quo or business-as-usual “Bioeconomy on the drip” scenario. Overcoming such skepticism will require communications tailored to specific groups and their respective concerns. Civil society will need to be engaged not only rationally but also emotionally in order to create the “bio-minded society” necessary for

transitioning to a bio-based economy. The challenge to involve citizens and stakeholders in co-design approaches, which lead to a socially acceptable transformation of the economy into a bio-based economy, is reinforced by the current funding structures in Germany [18]. Accordingly, we propose that society's perspectives could be much better accounted for by offering research groups the possibility to submit open proposals with the opportunity to involve society already in the early stages of the scientific process.

On the basis of our study results, we suggest that adaptations to a bio-based economy will gain a high level of acceptance among the German population if these adaptations, leading to an environment-oriented society that is also open to technological innovations. Promoting public interest in new technological possibilities is crucial, therefore, combined with efforts to raise awareness of people's individual responsibilities for their own social environments.

Given our finding that people's level of acceptance of bio-technical innovations increases with greater knowledge about such innovations and increased recognition of their usefulness [8,43], we further conclude that systematic efforts should be undertaken to increase public knowledge of proposed innovations and to communicate the values and usefulness of transitioning to a bio-based economy, including through dialogue that engages all societal groups.

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Appendix A

Table A1. Text provided in the pop-up windows of the scenarios.

Topic/Scenario	Bioeconomy on the Drip	Bioeconomy Islands	Bioeconomy Change
Bio-based products	People buy only a small amount of biobased products from renewable resources. Soap and plastics, etc., are mainly produced using fossil resources.	Some people mainly buy biobased products from renewable resources while others purchase cheaper fossil-based products.	People mainly buy biobased products. Soap and plastics, etc., are mainly produced from renewable resources.
Raw materials	For the production of everyday commodities, mineral oil is used as a raw material. Mineral oil is also sourced by fracking, i.e., fracturing the rock in an oil or gas reservoir with high water pressure via deep drilling to extract the oil/gas.	Renewable and fossil raw materials are used in equal proportions for the production of everyday goods. Renewable raw materials are mostly imported.	New technologies enable the use of mainly renewable raw materials for the production of everyday goods. The waste gas CO ₂ is captured and reused as a raw material. Algae are used as a raw material without the use of arable land. Waste is recycled.

Table A1. Cont.

Topic/Scenario	Bioeconomy on the Drip	Bioeconomy Islands	Bioeconomy Change
Energy	Fossil fuels cover most of our energy needs.	Renewable energies, especially bioenergy, cover most of our energy needs. Bioenergy is obtained from biomass from forestry and agriculture and plant residues.	Renewable energies, mainly based on hydrogen and recycling, cover most of our energy needs.
Consumption	We lead consumption-oriented lives with shopping as a hobby. We use products only briefly and throw them away quickly. We eat meat almost every day.	Some people lead consumption-oriented lives, including shopping as a hobby. Others live sustainably, reducing their consumption and engaging in recycling. We eat meat a maximum of four times a week.	We live sustainably and only buy what is necessary. We use products for as long as possible, repair them, and value reuse. We eat meat no more than twice a week.
Mobility	We drive private cars with combustion engines and continue to fly regularly.	We drive private cars mainly on electric power and continue to fly regularly.	We use low-cost, well developed public transport systems and car-sharing with hydrogen propulsion.
Land use	Additional arable land is needed for increasing animal production. Arable land and pastureland are expanding. Agriculture is characterized by monocultures and dominated by large livestock farms.	Additional arable land is needed for producing (renewable) raw materials and energy. There is reforestation in industrialized countries.	Organic agriculture accounts for the majority of production. Many nature reserves are newly designated.
Rain forests	Forests are being cut down in tropical countries to create additional arable land.	Renewable raw materials are largely imported, which is why arable and pastureland is expanding, especially in tropical countries, with rain forests being cleared for this purpose.	New technologies eliminate the need for additional arable and pasture land. There is reforestation at global level.

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