Public Understanding of and Attitudes Toward Bio-Based Labels and Claims

Prepared for the Plant Based Product Council*

by

Jayson L. Lusk, Ph.D.
jayson.lusk@gmail.com

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Executive Summary

Given the lack of harmonization and potential public confusion around terms used to describe the bioeconomy, this research aimed to determine consumer knowledge, beliefs, and preferences for the following 10 terms: biobased, biodegradable, bioeconomy, bioplastics, biopolymer, circular economy, compostable, organic, plant-based, and recyclable. A nationwide survey of about 1,500 U.S. residents, providing a sampling error of ±2.5%, was conducted in December 2022 to explore these issues. Key results are as follows.

- Self-assessed, subjective knowledge of bio-based related terms is low. About half the public has never heard the terms biopolymer, circular economy, or bioeconomy; more than half have either not heard or indicate not knowing the meaning of the terms biobased and bioplastics. By contrast, a majority of respondents said they were either somewhat or very knowledgeable of recyclable, organic, plant-based, biodegradable, and compostable.
- Generally, respondents indicated ignorance in knowing whether products that were biopolymers, bioplastic, biobased, or from the circular economy or bioeconomy were or could be recyclable, compostable, or organic.
- Responses to true/false and definition-matching questions reveal wide dispersion across the public in objective knowledge of bio-based and related terms. Only 0.6% of respondents answered 90% or more of the questions correctly. Forty six percent of respondents answered more questions incorrectly than correctly, and another 11% answered as many questing right as wrong. For example, only 27% of respondents correctly indicated it was false that "All biodegradable products are compostable."
- More respondents than not provided incorrect definitions for biodegradable, compostable, organic, and biobased. Respondents were particularly likely to mistake the definition of biodegradable for composable, biobased for organic, and plant-based for biobased.
    - White, non-Hispanics, middle-aged, higher educated individuals, particularly those with graduate degrees, exhibited higher objective knowledge of biobased and related terms, on average, than non-white, young, elderly, or people whose highest education was a high school degree.
- Compostable, plant-based, organic, biodegradable, and recyclable products were perceived to be high in sustainability and environmental friendliness; the opposite was true of animal-based and especially fossil-fuel based products. Recyclable and compostable products were viewed as relatively affordable whereas organic products were not. Recyclable products were perceived as relatively low in quality whereas organic was perceived as high quality.
    - Perceptually, respondents tend to view terms like organic and plant-based as being highly similar and related to another grouping of perceptually similar terms: biodegradable, compostable, and recyclable. Perceptually, respondents view all other terms with a "bio" prefix similarly: biobased, biopolymer, bioplastic, bioeconomy. Terms viewed as most dissimilar to the rest include circular economy, fossil-fuel based, and animal-based.
- There was strong public support for policies that would mandate packaging to indicate whether it is compostable, recyclable, or biodegradable; there was less, but still majority, support for mandatory labeling of whether a product is biobased.

- Simulated shopping choices indicate respondents are willing to pay significant premiums for take-away food in compostable, plant-based, or recyclable packaging while placing discounts on biobased and bioplastic packaging. Preferences for plant-based, compostable, and bio-based packaging are heavily influenced by the presence/absence of other label/claims, indicating consumers view these terms as having strong complementarity or substitutability relationships with other labels/claims.
    - Choices are significantly impacted by disclosures providing definitions of label terms. Providing definitional disclosures increased willingness-to-pay and choice likelihood for compostable packaging while having the opposite effect for biodegradable packaging, at least when these labels appeared in isolation.
    - Providing definitional information tends to reduce the size of the preference interactions between labels. When packaging already contains many competing claims/labels, provision of information disclosures increases the value of adding a new biobased claim in all instances. However, when adding a single label/claim in the absence of any others, definitional information reduces willingness-to-pay and choice probability for four terms (biodegradable, recyclable, plant-based, and biobased) while increasing it for two terms (bioplastic and compostable). These findings indicate definitional information tends to cause respondents to be more likely to value each term or label/claim on its own merits independent of other claims.

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1. Introduction

There is rising interest in environment, social, and governance (ESG) practices among firms, driven in no small part by demands among investors (Dow Jones, 2022; Wu, 2022). As a result, there is increased demand for activities and products related to circular- and bio-economies. Concurrently there is heightened interest in consumer and household sustainable behaviors and practices, which has spurred interest in sustainable, bio-based packaging, among other behaviors related to the circular economy (Boz et al., 2020; Polzin et al., 2023; Meherishi et al., 2019).

Nonetheless, adoption of many sustainability-related practices is still at low levels. For example, only 15% of U.S. households say they always compost food scraps, only 34% say they always recycle food packaging, and only 10% say they always choose plant-based over animal-based proteins (Polzin and Lusk, 2022). Moreover, adoption of practices, such as recycling, is strongly and positively correlated with education (Polzin and Lusk, 2022). As a result, there are questions about the extent to which consumers know about terms and practices related to the bio-economy.

Rising demand for sustainable products has led to the development of a range of bio-based products, including those associated with the bioeconomy, circular economy, and plant-based materials. These products often use terms such as biobased, bioplastics, biopolymer, compostable, recyclable, and biodegradable to describe their environmental benefits. While these terms may seem interchangeable, they often have very different meanings and implications for the environment. Understanding of these terms among business, regulators, and consumers may not always align with the intended meaning or the reality of the products' sustainability.

There is often confusion among consumers about the environmental benefits of biobased products, particularly in relation to terms such as compostable, recyclable, and biodegradable. For example, a product may be compostable, but this does not necessarily mean that it is recyclable. Similarly, a product may be biodegradable, but this does not necessarily mean that it is compostable. As a result, it is important to understand how consumers perceive and understand these and other terms, as well as the extent to which their perceptions align with the actual environmental impacts of the products they purchase.

Conducting research on consumer knowledge and perceptions of bio-based products is important for several reasons. First, consumer understanding and perceptions can significantly impact purchasing decisions and the market demand for these products. The use of misleading or ambiguous terms may lead to consumer confusion or mistrust, potentially undermining the credibility and effectiveness of the biobased products market. Second, as regulatory bodies at local, state, and federal levels adopt sustainability initiatives to promote the bioeconomy, it is important to understand the extent to which the public is aware and knowledgeable of different terms and concepts used to describe the circular economy. Differences in regulation across states and locales might further lead to confusion as different labels are used to signify whether a product is compostable, and in one instance (California), products will soon only be deemed compostable if they are also organic. Finally, a better understanding of consumer knowledge and perceptions can inform the development and communication of sustainable products, ensuring that they accurately reflect the environmental benefits claimed and meet consumer expectations.

Accordingly, this paper reports the results of a nationally-representative survey of the U.S. population. The primary objective of study is to determine consumer knowledge, perceptions, and preferences associated with 10 key terms: biobased, biodegradable, bioeconomy, bioplastics, biopolymer, circular economy, compostable, organic, plant-based, and recyclable. The next section describes the methods used to accomplish the study objectives. Discussion of results immediately follow.

2. Methods

In December 2022, a survey of the U.S. population was conducted to accomplish the study objectives. The survey was written and programmed in the online Qualtrics platform and was administered to a sample of respondents maintained by the panel provider, Prolific. Prolific was chosen because prior research indicates this platform significantly outperformed four other prominent survey panels in terms of a variety of metrics related to data and response quality (Peer et al., 2022). 1,500 completed responses were targeted. This sample size provides a ±2.5% sampling error, meaning that the share of sampled respondents measured to fall in a particular category is within 2.5% of the true population with 95% certainty.

There were three exclusionary criteria that resulted in a respondent's omission from the analysis. First, respondents had to respond affirmatively to an informed consent form indicating a willingness to participate in the study. Second, respondents had to pass an "attention check" that asked them to match shapes with their respective names. Third, respondents had to answer more than half of the survey questions. The final usable sample size consists of responses from 1,498 respondents. Data were collected from December 1 to December 4, 2022.

Two steps were taken to ensure the sample was representative of the U.S. population. During data collection, quotas were used to ensure respondents were representative of the population in terms of broad categories related to age, gender, and ethnicity (particularly, the share Black or African American). Then, after the sample was acquired, then survey weights were created using the approach described in Battaglia et al. (2009). In particular, weights were created to force the sample to match the population, as determined by the 2021 U.S. Census Current Population Survey, along the following dimensions: geography of residence (defined by 9 Census divisions), gender (percent female), age, education, race (Hispanic status; and White vs. Black vs. other), and income. A map showing which states fall each census division is available here. Table 1 shows the characteristics of the sample compared to the characteristics of the U.S. population and then shows the characteristics of the sample after weights are applied. By construction, after weighting the sample exactly matches the population in terms of those variables used to construct the weights.

Table 2.1 Demographic Characteristics of Survey Respondents

Demographic	US Census[a]	Unweighted (N=1,498)	Weighted (N=1,498)[b]
inc<$60k	43.6%	53.1%	43.6%
$60k≤inc<$100k	22.4%	25.6%	22.4%
inc≥$100k	34.0%	21.4%	34.0%
18≤age≤25	11.7%	11.5%	11.7%
25≤age≤34	17.4%	20.2%	17.4%
35≤age≤44	16.9%	17.7%	16.9%
45≤age≤54	15.7%	16.8%	15.7%
55≤age≤64	16.6%	19.6%	16.6%
65≤age	21.6%	14.2%	21.6%
HHsize=1	28.3%	23.4%	28.3%
HHsize=2	34.2%	32.5%	34.2%
HHsize=3	15.4%	21.0%	15.4%
HHsize≥4	22.1%	23.1%	22.1%
HS edu or lower	38.0%	14.4%	38.0%
some college or associates	29.5%	32.9%	29.5%
BS or BA	20.3%	37.0%	20.3%
MS, MA, PhD, JD, etc.	12.2%	15.8%	12.2%
Female	51.0%	49.9%	51.0%
White	61.2%	79.2%	61.2%
Black	12.1%	13.4%	12.1%
All Other	26.7%	7.4%	26.7%
Hispanic	18.8%	5.5%	18.8%
New England Division	4.5%	4.7%	4.5%
Middle Atlantic Division	12.7%	13.8%	12.7%
East North Central Division	14.2%	16.2%	14.2%
West North Central Division	6.5%	5.3%	6.5%
South Atlantic Division	20.1%	22.6%	20.1%
East South Central Division	5.9%	6.9%	5.9%
West South Central Division	12.4%	10.6%	12.4%
Mountain Division	7.6%	5.9%	7.6%
Pacific Division	16.1%	14.0%	16.1%

[a]Census data defined by 2021 Current Population Survey
[b]Weights are created based on all the characteristics shown in the table except household size.

The survey began with a consent form and a brief description of the issue to be studied. The following preliminary stage-setting paragraph was provided:

> "Today, a wide diversity of consumer products can be made with plant-derived ingredients including hard plastics used in toys, furniture or automobiles, soft plastics used in water bottles or packaging, cosmetics, construction materials, electronics, disposable diapers, bedding, disposable plates and cups, and much more. We want to know your thoughts about these products and the terms sometimes used to describe them."

The first main section of the survey was designed to measure knowledge and understanding about the following 10 terms: biobased, biodegradable, bioeconomy, bioplastics, biopolymer, circular economy, compostable, organic, plant-based, and recyclable. In various questions, these terms were also contrasted with two other terms, animal-based and fossil fuel-based, and in one instance they were compared to a made-up word, fimeratable, created from an online random fake word generator. Questions were written to probe subjective and objective knowledge of the 10 terms. Because a main objective of this research was to determine knowledge and possible misperceptions of biobased terms and concepts, most of the survey questions allowed an "I don't know" option so as to insure accurate/inaccurate responses represent true knowledge (or not) rather than lucky/unlucky guessing. To prevent order effects, the order in which the items appeared varied randomly across respondents.

To further probe public understanding of bio-based and related terms, the last question of this section asked respondents to match each of the 10 terms with their associated definitions (this particular question did not have an "I don't know" option). Term definitions were taken from the Plant Based Product Council's glossary. Figure 2.1 shows a screenshot of this particular question. The order in which definitions were presented was varied randomly across participants to prevent an order effect.

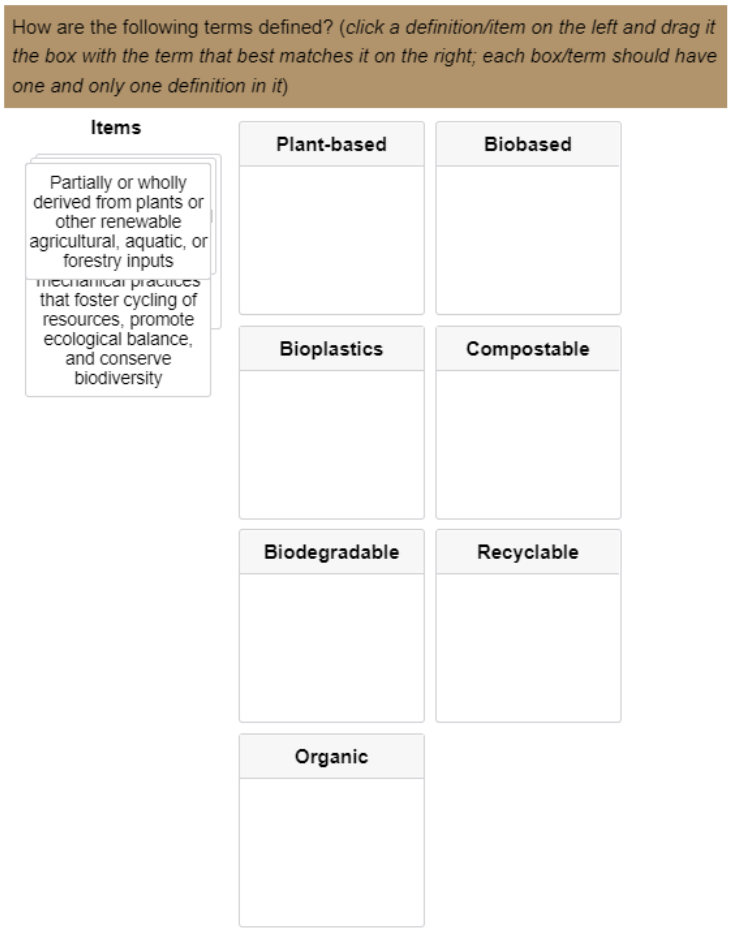

Figure 2.1 Screenshot of Definition Matching Exercise

A second section of questions probed respondent's beliefs and perceptions of the aforementioned 10 terms in addition to animal-based and fossil fuel-based. Respondents were asked to rate each of the terms along dimensions related to perceived sustainability, environmental friendliness, quality, and affordability. Responses were recorded on a five-point scale from, e.g., very unsustainable to very sustainable; respondents could also select an "I don't know" option. After removing those who indicated "I don't know", responses were coded from -2 (e.g., very unsustainable), -1 (e.g., somewhat unsustainable), 0 (e.g., neither sustainable to unsustainable), +1 (e.g., somewhat sustainable), to +2 (e.g., very sustainable).

To further explore beliefs and perceptions about these terms, respondents were also asked to complete a "pile sorting" exercise. Pile sorting is a technique commonly used in small-scale, qualitative interviews in diverse fields from anthropology to psychology (e.g., Boster, 1994; Hosoya et al., 2017; Yeh et al., 2014), and it was adapted for use in the large-scale nationally representative survey employed in this study. In particular, respondents were asked to group the 12 aforementioned items according to how similar they were. Respondents were asked to click and drag each item into one of four boxes, putting items the respondent felt were most similar to each other in the same box using as many or as few boxes as they liked. Figure 2.2. shows a

screenshot of the pile-sorting decision task. As before, the order in which the 12 items were presented was randomly varied across respondents.

To analyze the pile-sorting data, a diagonal "similarity matrix" was constructed which counted the number of times each item appeared together with every other item in a group/pile. This similarity matrix was then used to implement ordinal multidimensional scaling, which provides a representation of the similarity and dissimilarity of objects (or, in this case, biobased terms) in N-dimensional space (for simplicity, only two-dimensional outcomes are reported in this paper). In addition, hierarchical cluster analysis was applied to the similarity matrix to further explore how similar/dissimilar were the 12 items. The purpose of these two analyses is to uncover how respondents perceptually view these items in relation to one another.

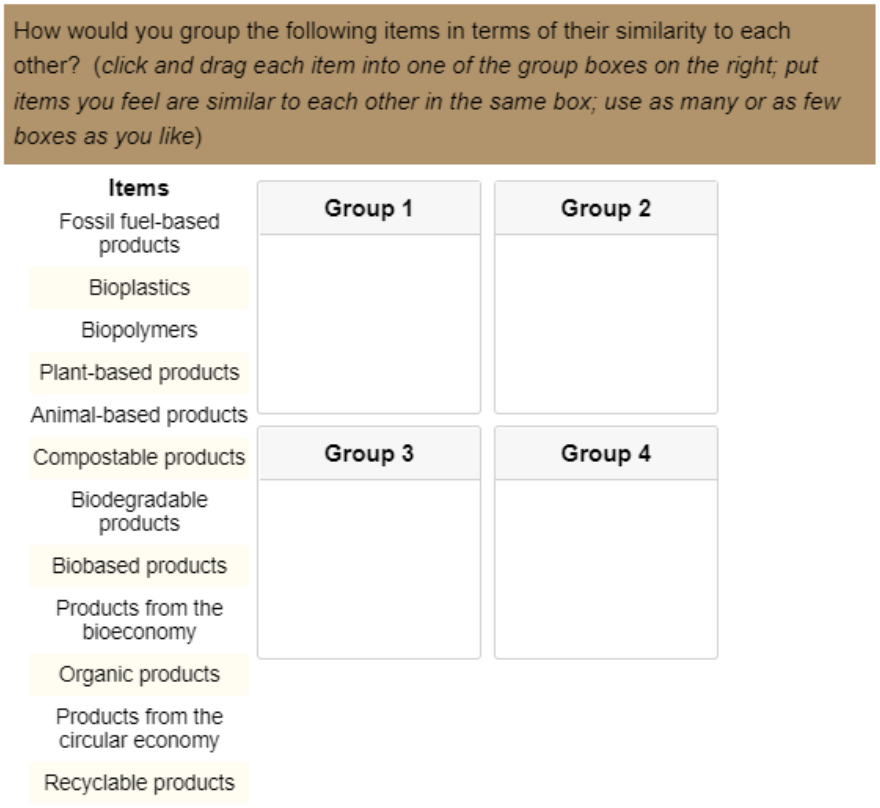

Figure 2.2 Screenshot of Pile Sorting Exercise

A penultimate section of the survey sought to measure respondent's preferences for policies and products. The first question set measured consumers' support or opposition to hypothetical policies that would require disclosure of whether a product was recyclable, compostable, biodegradable, or biobased.

The second set of questions implemented the so-called choice experiment (CE) method that has been widely adopted in economics and marketing literatures to estimate consumers' attribute-based preferences (Louviere et al., 2020). The CE method has been shown to be less sensitive to hypothetical bias than other question techniques and to be highly predictive of actual consumer purchase behaviors (Brooks and Lusk, 2010; Chang et al., 2008; Lusk and Schroeder, 2004).

The CE entails asking respondents to take part in a simulated shopping scenario in which they are asked to make a choice between two or more products that differ along a number of attributes or characteristics.

In this study, respondents were asked to choose between take-away meals at three different restaurants that were identical except the type of packaging used. Packaging could have one or more of six different labels/clams (or none): biobased, bioplastic, biodegradable, recyclable, plant-based, and/or compostable. In addition, meals differed by price, ranging from $10 to $20.

Given the presence/absence of the six labels and varying prices across the three different restaurants, there are thousands of possible choice combinations that could be created for respondents to evaluate. To reduce the burden on respondents and to efficiently estimate preference parameters, an experiment design was created using the software ngene. In particular, a D-efficient design was chosen that permitted the estimation of all linear and two-way label effects. The resulting design consisted of 24 choice questions, which were blocked into three groups of eight questions. Each survey respondent was randomly assigned to one of the blocks, and each respondent answered eight choice questions.

A preamble to the choice questions read as follows.

Imagine you are ordering take-out lunch from a local restaurant. You must choose between three restaurants that are identical to each other except for the plates, forks, cups, and packaging material they use to serve and deliver the food.

Each restaurants makes different claims about the materials used to manufacture their dishware and packaging material. Otherwise, assume the food is exactly the same in type and quality for all three restaurants.

Below, you will make 8 choices that are similar except the mix of meal prices and type of dishware and packaging materials offered by competing restaurants.

To study the effect of knowledge and information, half the sample was randomly assigned to a control CE in which no additional information was provided about the terms/labels used to define the packaging. A second group of respondents was randomly assigned to a treatment group, in which definitions of each label were provided immediately below each choice question. Figure 2.3 shows a screenshot of one of the choice questions used in the treatment condition. The questions asked in the control condition were identical except for the omission of the definitions that immediately followed each question.

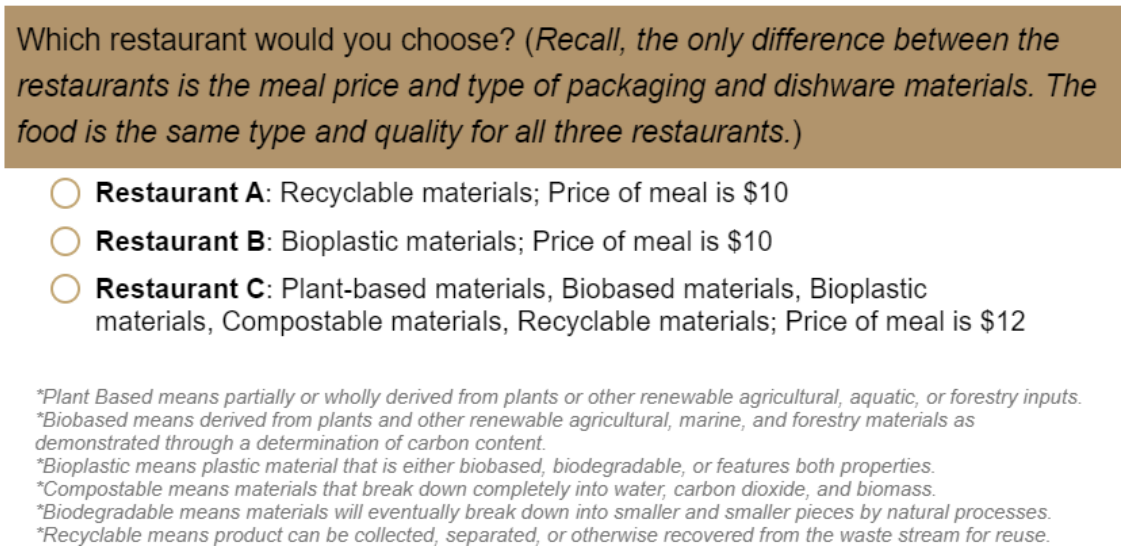

Figure 2.3 Screenshot of Example Choice Question Including Term Definitions

Choice data from the CE are analyzed using a multinomial logit (MNL) random utility model (RUM) framework. The MNL model estimates the parameters of a random utility function, which shows how respondents' preferences for a restaurant option vary with the presence/absence of the six labels and price. In addition to the linear label effects, we also include all 2-way interaction effects, which allow, say, the preference for compostable packaging to vary depending on whether the packaging is also recyclable. Positive interaction effects indicate two labels are complements (people's preferences are super-additive, and packaging with the two labels together is more preferred than what would be suggested by the linear sum of the two independent label effects). Negative interaction effects indicate two labels are substitutes (people's preferences are sub-additive, and packaging with the two labels together is less preferred than what would be suggested by the linear sum of the two independent label effects). Substitution effects occur when, for example, respondents perceive one label provides many of the same benefits as another label.

Given that respondents are randomly assigned to an information treatment or control, models are estimated separately for each treatment and a likelihood ratio test is used to determine whether preferences and resulting choice probabilities are affected by provision of label definitions.

Once attribute-based utility functions are estimated, willingness-to-pay is calculated for each label. Willingness-to-pay is determined by identifying the price difference between two restaurant options that would make a respondent indifferent between the two restaurants that are identical except for the presence/absence of the label. Because the utility function includes label interaction effects, willingness-to-pay for a label depends on the presence/absence of all other labels.

The estimated utility function can also be used to calculate probability of choice. Two such calculations are made to determine the relative importance of each of the labels. The first calculation assumes there are two restaurants: restaurant A has packaging displaying all 6 labels and charges $15; restaurant B has packaging displaying all but one of the 6 labels and also charges $15. The probability of choosing restaurant A and B, and the resulting odds of choosing A over B, is calculated. This calculation is repeated where restaurant B varies which label is absent. The higher the odds of choosing A over B, the more important is the omission of the particular label. The second exercise is similar except it starts with a baseline of no labels (and thus no interactions). Assume there are two restaurants: restaurant C has packaging with no labels and charges $15; restaurant D has packaging with only one of the 6 labels and also charges $15. The probability of choosing restaurant C and D, and the resulting odds of choosing D over C, is calculated. This calculation is repeated for all six labels. The higher the odds, the more important is the addition of the particular label. Comparing the first to the second set of calculations provides an indication of the importance of interaction effects in label evaluations.

A final section of the survey asked a standard set of socio-economic and demographic questions.

3. Results

Presentation of results is broken down in three sub-sections associated with sets of questions that probed knowledge, beliefs, and preferences, beginning with presentation of results about knowledge. Results are presented for the primary questions of interest in visual form. For the interested reader, topline results reporting the share of respondents falling in every response category for every question asked in the survey is provided in a separate document here; this document also shows the exact wording of every question and provides a codebook for analysis.

3.1 Knowledge

After some introductory material, the initial question asked how familiar respondents were with 11 terms. Results of this self-assessed subjective knowledge question are shown in figure 3.1.1. One of the terms, fimertable, was fictitious and created by an online fake word generator; the term was added as a validity check. 85% of respondents said they'd never heard the word and 5% said they didn't know; only 1% said they were very knowledgeable of this fake term. These findings suggest respondents were attentive and that statements of self-assessed knowledge are indeed reflective of high subjective levels of knowledge and not a reflection of random responses or social desirability bias.

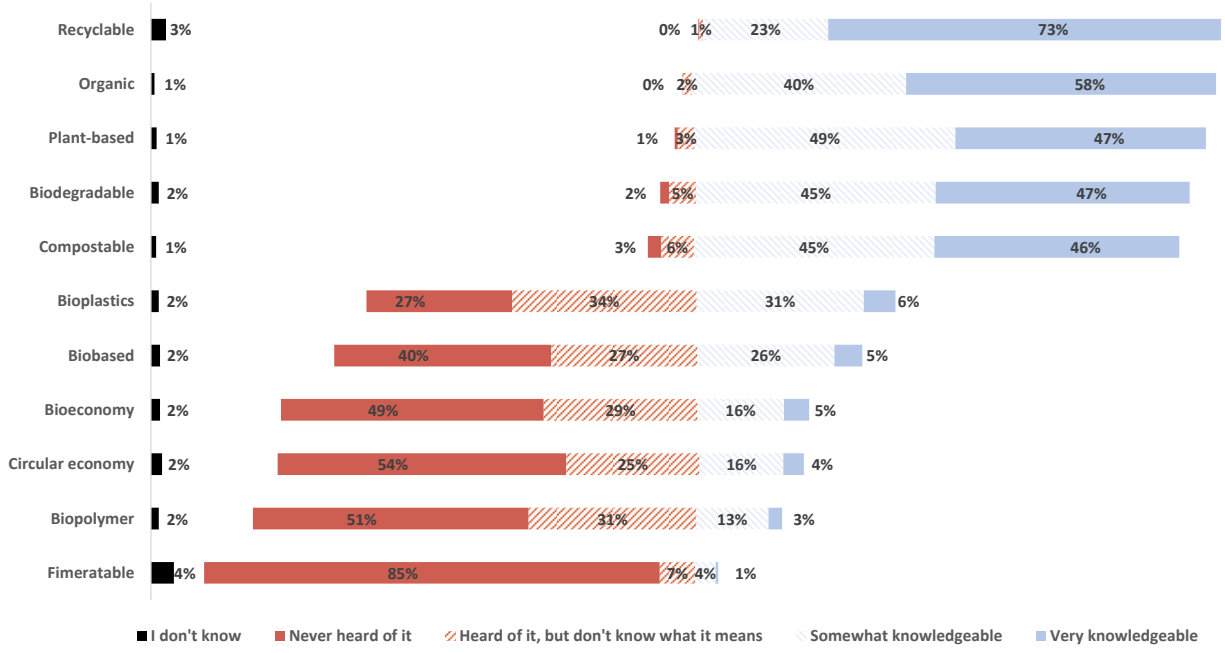

Figure 3.1.1 Self-Assessed Subjective Knowledge of and Familiarity with Bio-Related Terms

Figure 3.3.1 suggest low levels of subjective knowledge of terms like biopolymer and circular economy; more than 50% said they have not heard of the terms. Likewise, terms like bioeconomy, biobased, and bioplastics were unfamiliar, with more than 50% of respondents indicating they either had not heard the term or did not know what it meant. There were higher

levels of subjective knowledge of terms like compostable, biodegradable, plant-based, organic, and recyclable. Over 70% of respondents indicated being "very familiar" with recyclable. Whether high levels of subjective knowledge comport with high objective knowledge levels is another matter and one that is probed in subsequent questions.

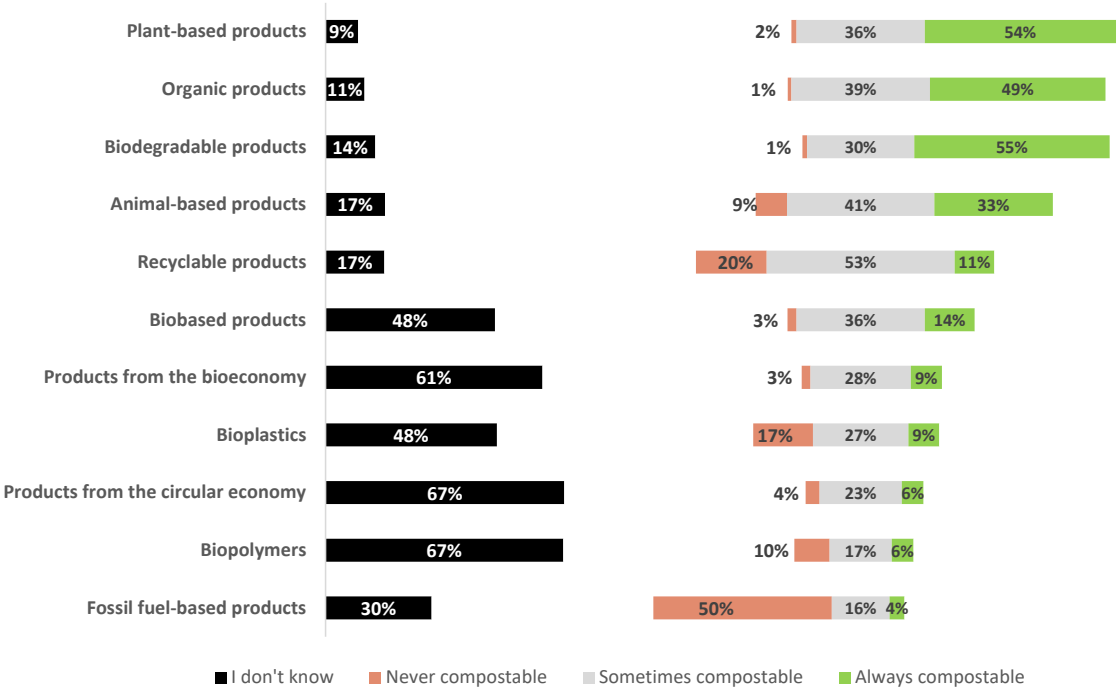

Figure 3.1.2 Are the Following Products *Compostable*?

Figure 3.1.2 reports results of question asking whether products with 11 claims are compostable. The obvious question of whether compostable products are compostable was not asked. More than half of the respondents thought plant-based products were always compostable. Only 36% of respondents accurately indicted plant-based products are sometimes compostable. Similar outcomes were observed for organic and biodegradable products. 55% of respondents thought biodegradable products were always compostable, but in reality not all biodegradable products are, in fact, compostable. Two thirds of respondents did not know whether products from the circular economy or biopolymers were compostable. Similarly, large percentages of respondents did not know whether biobased products from the bioeconomy, or biobased plastics were compostable. Half the respondents correctly indicated that fossil fuel-based products are never compostable.

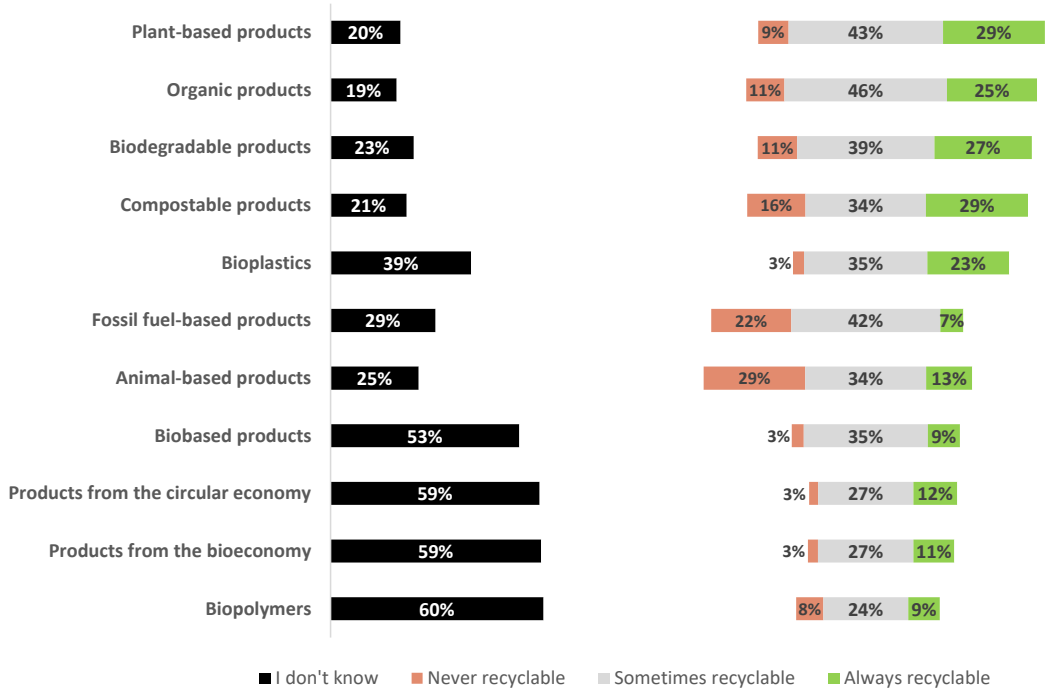

Figure 3.1.3 Are the Following Products *Recyclable*?

Respondents were asked whether each of 11 products were recyclable (see figure 3.1.3). More than half of respondents did not know whether biobased products, products from the circular economy, products from the bioeconomy, or biopolymers were recyclable. Respondents were most likely to think plant-based and organic products are recyclable.

Figure 3.1.4 shows the results associated with whether respondents believed each of the 11 products are organic. A majority of respondents correctly indicated that recyclable products, biodegradable products, compostable products, animal-based products, and plant-based products are sometimes recyclable. Nonetheless, a majority of respondents indicated they did not know whether biopolymers, bioplastics, products from the circular economy, products from the bioeconomy, biobased products were or could be organic.

Whether products are believed to be made from plants is reported in figure 3.1.5. Forty nine percent or more of respondents indicated that they did not know whether the following was made from plants: biopolymers, products from the circular economy, bioplastics, products from the bioeconomy, and biobased products. Two thirds of respondents said an animal-based product could never be made from plants; 49% said the same of fossil-fuel based products. A majority of respondents thought the following were sometimes made from plants: recyclable products, biodegradable products, compostable products, and organic products. 83% of respondents said plant-based products are always made from plants.

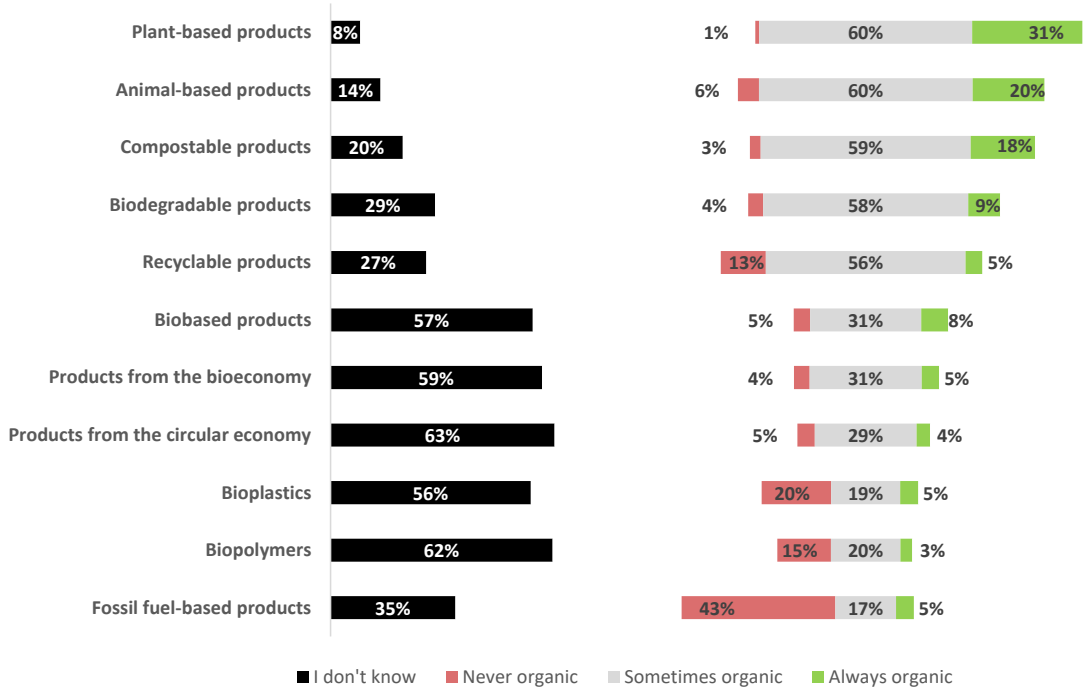

Figure 3.1.4 Are the Following Products *Organic*?

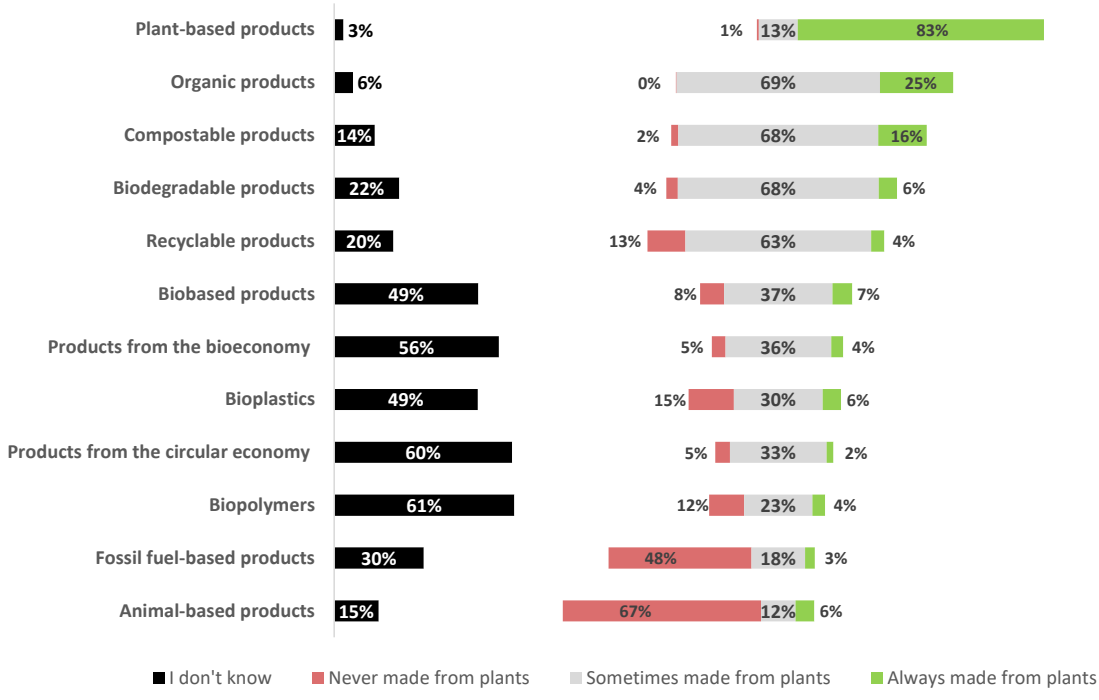

Figure 3.1.5 Are the Following Products *Made from Plants*?

Figures 3.1.6 through 3.1.9 report whether respondents thought particular products were never, rarely, sometimes, often, or always recyclable, compostable, etc.

Figure 3.1.6 shows respondent's knowledge of hemp-derived products. 63% of respondents said a product made from hemp is plant-based. A majority of respondents indicated a product made with hemp is never animal- or fossil-fuel based. 40% or more respondents indicated they did not know whether a product made from hemp is or could be a bioplastic, biopolymer, product of the circular economy, product of the bioeconomy, or biobased.

Figure 3.1.7 shows respondent's knowledge of a product made with corn, soybeans, or sugarcane. Results are broadly similar to respondents' views about hemp. In both cases, more than a third of respondents incorrectly thought these products could never or rarely be a bioplastic.

More than half of respondents did not know whether a product made with petroleum was a biopolymer, a product of the circular economy, or a product of the bioeconomy (figure 3.1.8); more than 40% did not know whether a product made with petroleum was biobased or a bioplastic. A majority of respondents said a product made with petroleum was never animal-based, compostable, or organic. Curiously, only 61% of respondents thought a product made with petroleum was always fossil fuel based.

90% of respondents correctly indicated a product made with cattle byproducts (e.g., fat, bone, hoof, hide) is often or always animal based (figure 3.1.9). More than half of respondents did not know whether a product made with cattle byproducts was a biopolymer, a product of the circular economy, biobased, or a product of the bioeconomy. Forty percent thought a product made with cattle byproducts could never be a bioplastic.

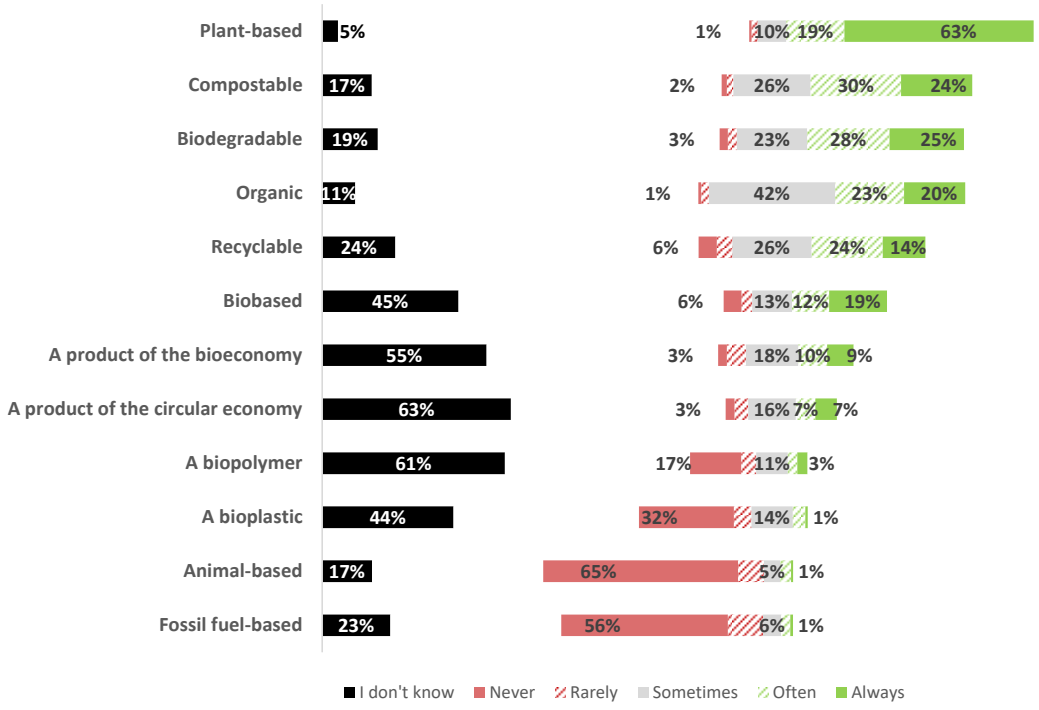

Figure 3.1.6 A Product Made from *Hemp* is …

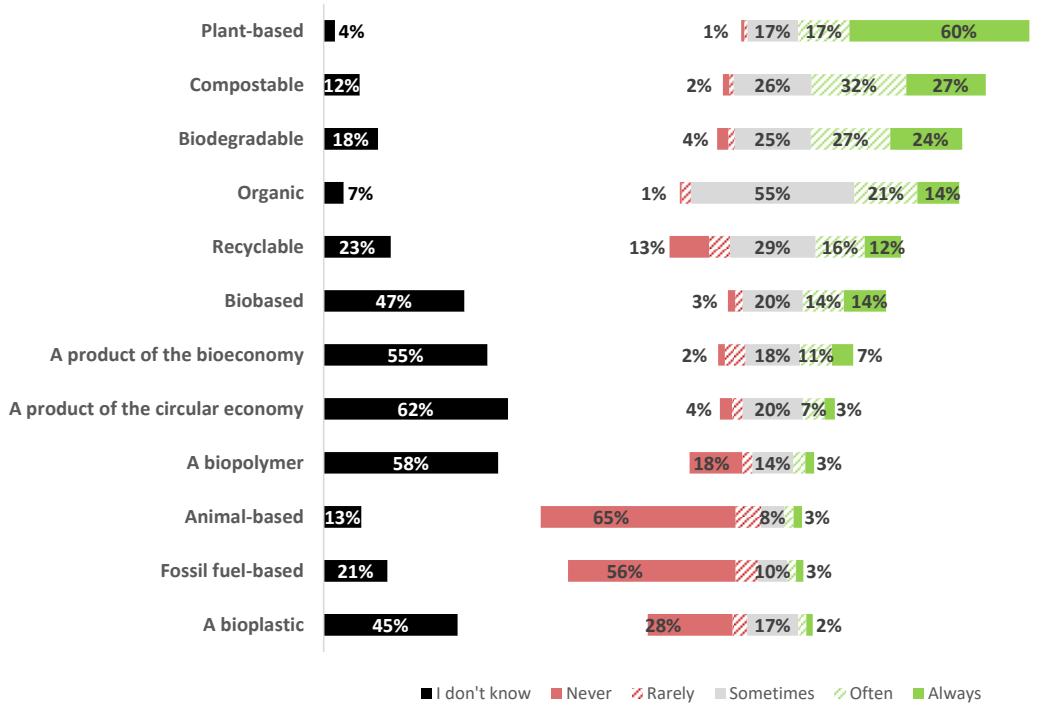

Figure 3.1.7 A Product Made with Corn, Soybeans, or Sugarcane is …

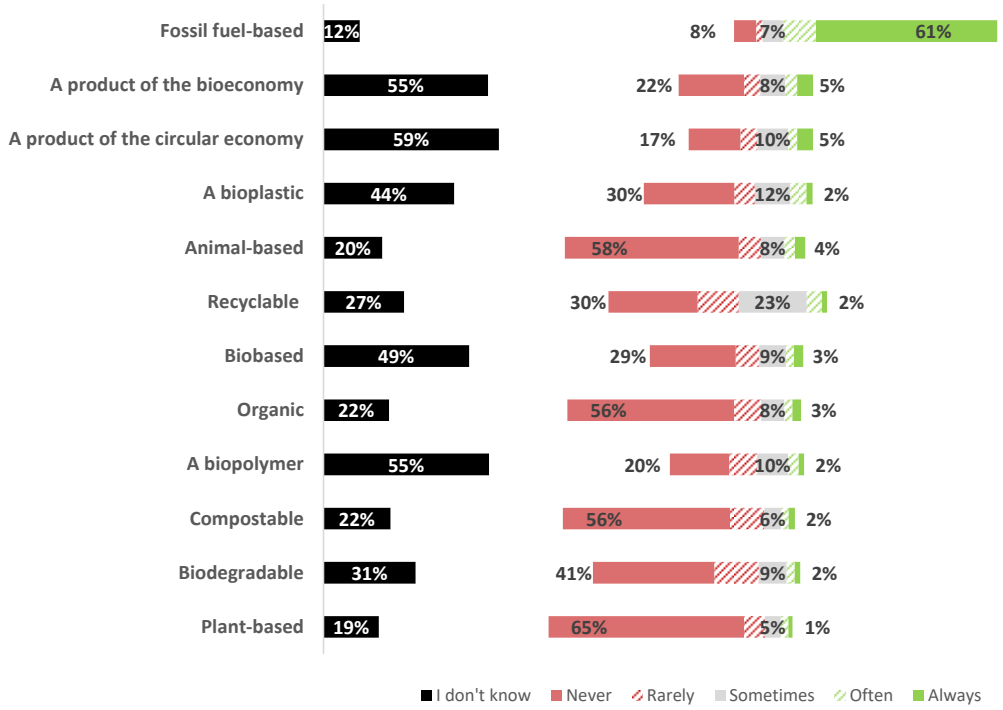

Figure 3.1.8 A Product Made with Petroleum is …

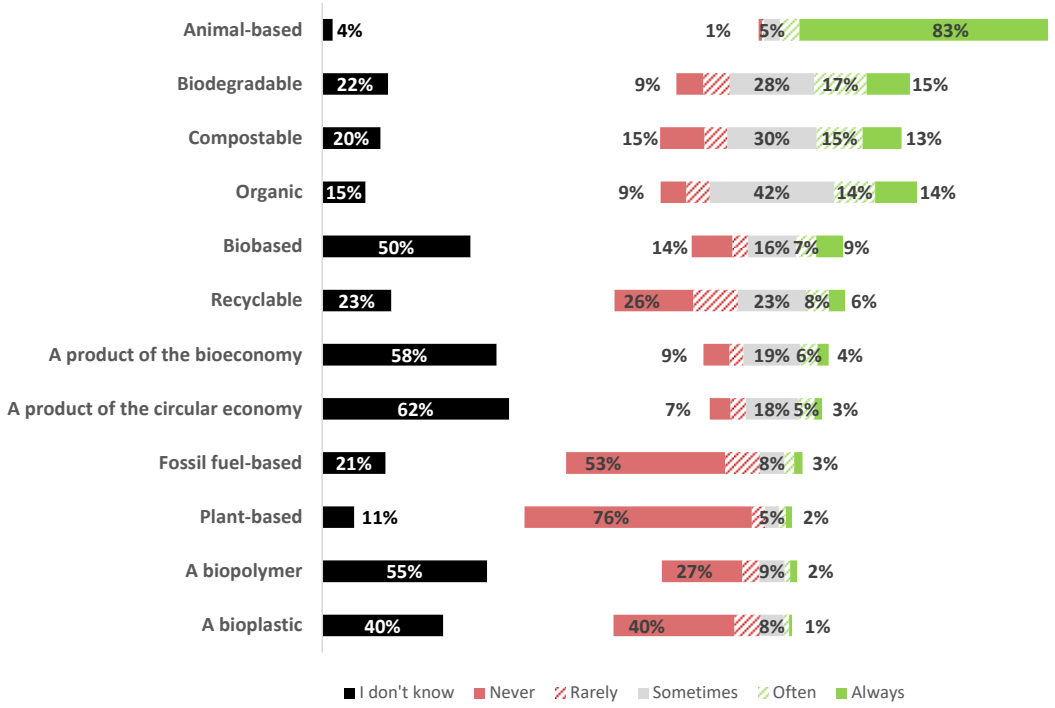

Figure 3.1.9 A Product Made with Cattle Byproducts (e.g., Fat, Bone, Hoof, Hide) is …

While the results in figures 3.1.2 through 3.1.9 provide indications of respondent's objective knowledge, whether a particular response is objectively right or wrong is ambiguous in many cases given categories such as "sometimes" and "seldom." To hone in on a more unambiguous measure of objective knowledge, two additional sets of questions were asked. The first requested respondents match pre-populated definitions with the correct term. Specifically, respondents were asked to click a definition/item on the left-hand side of the screen and drag it the box with the term that best matches it on the right (see figure 2.1). Table 3.1.1 shows the key results from this definition-matching task.

About three-quarters of respondents correctly matched the terms bioplastics and recyclable with their respective definitions, and 55.6% did the same for plant-based. However, more respondents than not provided incorrect definitions for biodegradable, compostable, organic, and biobased. Respondents were particularly likely to mistake the definition of biodegradable for composable, biobased for organic, and plant-based for biobased. In fact, more people assigned the term biobased to the definition for organic than did the number of people correctly assigning the definition of organic to organic. The same was true for people choosing plant-based for the biobased definition. Similarly, only 36.9% of respondents correctly assigned the correct definition to compostable, and almost the same percent, 36.7%, incorrectly assigned the definition of compostable to the term biodegradable.

Table 3.1.1 Matching of Terms to Definitions

Definition	**Correct Answer (% Choosing)**	**Most Common Incorrect Answer (% Choosing)**
Plastic material that is either biobased, biodegradable, or features both properties	Bioplastics (76.4%)	Biobased (9.5%)
Product can be collected, separated, or otherwise recovered from the waste stream for reuse	Recyclable (75.2%)	Compostable (9.1%)
Partially or wholly derived from plants or other renewable agricultural, aquatic, or forestry inputs	Plant-based (55.6%)	Organic (20.7%)
Materials will eventually break down into smaller and smaller pieces by natural processes	Biodegradable (43.2%)	Compostable (36.0%)
Materials that break down completely into water, carbon dioxide, and biomass	Compostable (36.9%)	Biodegradable (36.7%)
Product has been produced through approved methods that attempt to integrate cultural, biological, and mechanical practices that foster cycling of resources, promote ecological balance, and conserve biodiversity	Organic (31.1%)	Biobased (31.6%)
Derived from plants and other renewable agricultural, marine, and forestry materials as demonstrated through a determination of carbon content	Biobased (24.8%)	Plant-based (37.4%)

In addition to the definition matching task, respondents were asked a series of true/false questions (see figure 3.1.10). 63% of respondents correctly indicated that all compostable products are biodegradable; however, 58% incorrectly indicated all plant-based products are compostable. Only 27% of respondents correctly indicated it was false that "All biodegradable products are compostable."

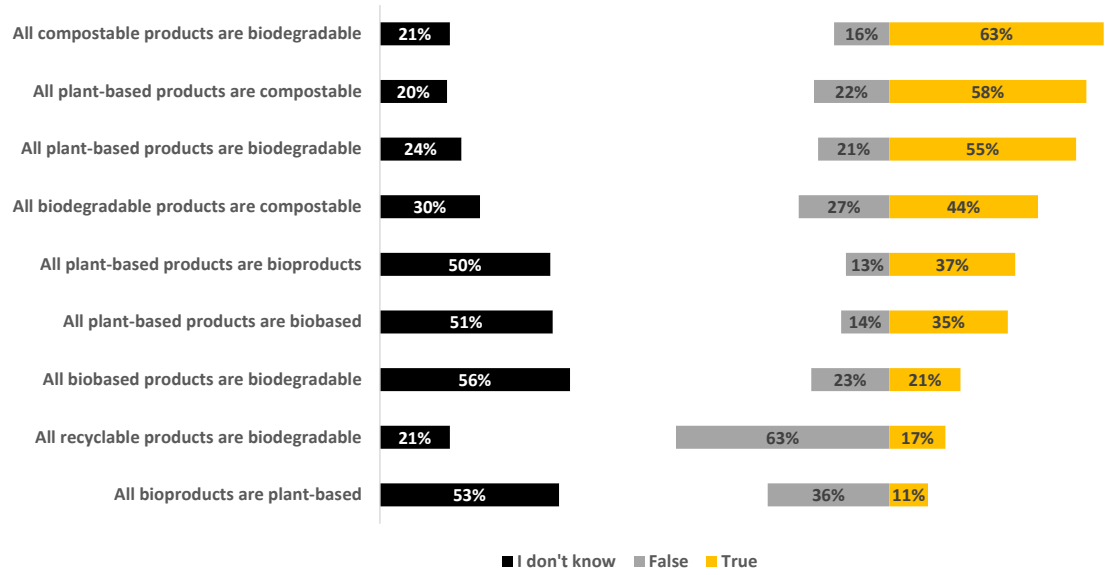

Figure 3.1.10 Are the Following Statements True or False?

Responses to the questions shown in table 3.1.1 and figure 3.1.10 were used to construct a measure of objective knowledge. For each definition that was correctly matched to a term, the respondent's knowledge score was increased one point; for each definition that was incorrectly matched to a term, the respondent's knowledge score was reduced one point. For each true/false question correctly answered, the score was increased by one. For each true/false question correctly answered, the score was reduced by one. If a respondent indicated "I don't know" to a true/false question, their knowledge score was neither increased or decreased. Given the seven definitions and nine true/false questions, the maximum possible score is +16 and the lowest possible score is -16.

Figure 3.1.11 shows the distribution of knowledge scores. Only 0.3% of respondents got all 16 questions correct; another 0.3% got all but one question correct. Thus, only 0.6% of the respondents got 90% or more of the questions correct. Forty six percent of respondents answered more questions incorrectly than correctly, and another 11% had a score of zero, meaning they answered as many questing right as wrong. The three most common scores were 0, -2, and -4. Nobody got all 16 questions incorrect.

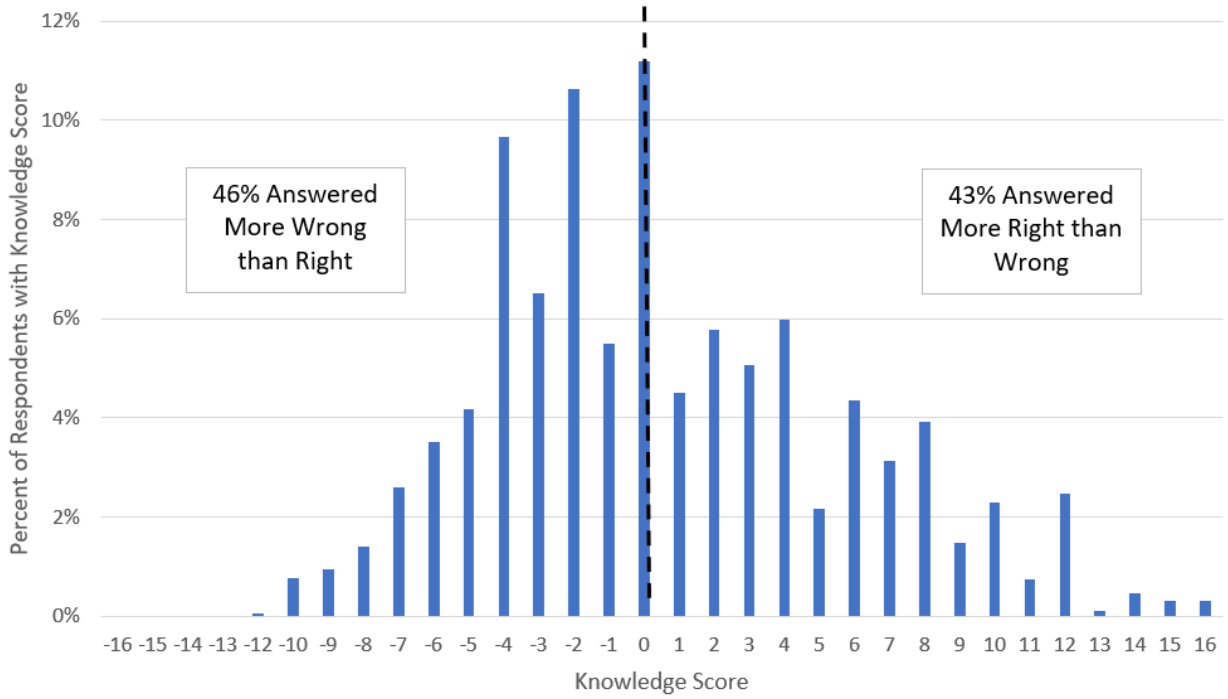

Figure 3.1.11 Distribution of Knowledge Scores

To explore heterogeneity in objective knowledge, table 3.1.2 shows the mean knowledge score for a number of socio-economic and demographic categories. In addition, p-values associated with the null hypothesis that the mean knowledge scores are identical within a demographic category are reported; values less than 0.05 are deemed statistically significant, meaning knowledge differences across levels of a demographic category are unlikely to be the result of chance.

Knowledge scores did not significantly vary by income. Middle-aged respondents (aged 35 to 54) had higher scores than the young (younger than 25) or elderly (55 and older). Single-person households had higher average knowledge scores than more populated households. Education had large effects on knowledge. Whereas individuals with a graduate degree had an average knowledge score of 3.14, individuals who only had a high school degree or less had an average knowledge score of -0.57. Knowledge scores were higher, on average, among white, non-Hispanic individuals. Gender and geographic region of residence were not significantly associated with variation in knowledge scores.

Table 3.1.2 Mean Knowledge Score by Demographic Characteristics

Demographic	Mean Knowledge Score	p-value[a]
inc<$60k	0.60	
$60k≤inc<$100k	0.49	0.68
inc≥$100k	0.79	
18≤age<25	0.48	
25≤age<34	1.03	
35≤age<44	1.62	<0.01
45≤age<54	1.19	
55≤age<64	0.27	
65≤age	-0.48	
Hhsize=1	1.57	
Hhsize=2	0.23	<0.01
Hhsize=3	-0.23	
Hhsize≥4	0.67	
HS edu or lower	-0.57	
some college or associate degree	0.82	<0.01
BS or BA	1.12	
MS, MA, PhD, JD, etc.	3.14	
Female	0.83	0.14
Male/Other	0.44	
White	0.85	
Black	-0.34	0.02
All Other	0.59	
Hispanic	0.98	<0.01
Not Hispanic	-0.84	
New England Division	0.71	
Middle Atlantic Division	0.56	
East North Central Division	0.59	
West North Central Division	1.20	
South Atlantic Division	0.93	0.38
East South Central Division	0.87	
West South Central Division	-0.13	
Mountain Division	1.22	
Pacific Division	0.36	

[a]P-value from F-test associated with the null hypothesis that the mean knowledge score is the same for all categories within a demographic variable.

3.2 Beliefs

Respondents were asked to rate products associated with each of 12 terms on 5-point scales related to sustainability, environmental friendliness, affordability, and quality. Figure 3.2.1 shows the results related to sustainability. More than half of respondents indicated they did not know whether biopolymers or products of the circular economy were unsustainable or sustainable, but among those who did express a belief, the average sustainability score (ranging from -2 to +2) was 0.42 for biopolymer and 0.84 for products from the bioeconomy. The highest average sustainability scores were for plant-based products and compostable products, followed closely by organic and biodegradable products. The lowest average sustainable score (-1.17) was for fossil fuel-based products. All products, except fossil-fuel-based products, were, on average, believed to be more sustainable than not, at least among those respondents who did not select "I don't know."

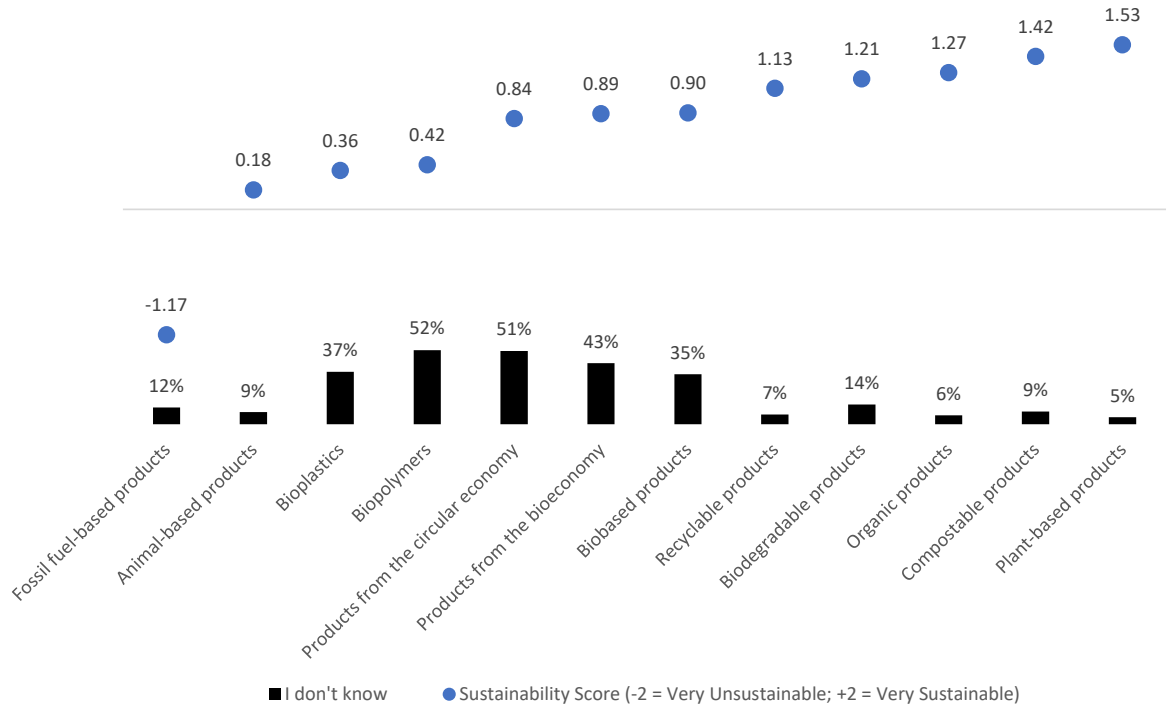

Figure 3.2.1 Are the Following Products Unsustainable or Sustainable?

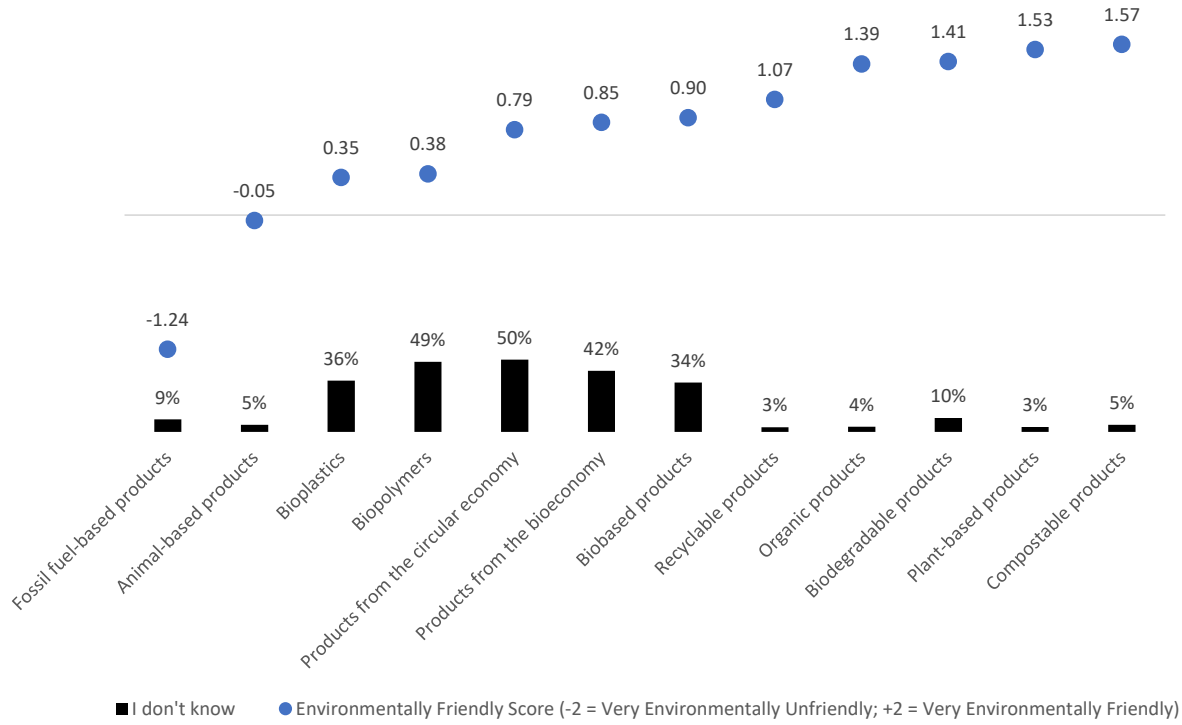

Figure 3.2.2 Are the Following Products Environmentally Friendly or Unfriendly?

Figure 3.2.2 shows the average beliefs for how each of the products rate on environmental friendliness. Overall, results are similar to that for sustainability. Indeed, the correlation between average sustainability and environmental friendliness scores is 0.99 (see the upper left-hand side panel of figure 3.2.4), suggesting individuals view these two terms as highly similar if not identical constructs. Nonetheless, environmental friendliness scores for the top products (compostable, plant-based, biodegradable, and organic) are higher than average sustainability scores. Animal-based products are viewed, on average, as slightly more environmentally unfriendly than environmentally friendly.

Figure 3.2.3 shows perceptions of affordability. Recyclable products are viewed as most affordable, followed by compostable and animal-based products. Organic products are viewed as least affordable, and are perceived as more unaffordable, on average, than affordable. Perceptions of quality are shown in figure 3.2.4. Organic products are viewed as highest quality and fossil-fuel based and recyclable products are perceived as lowest quality. All 12 products are viewed, on average, as more high than low quality.

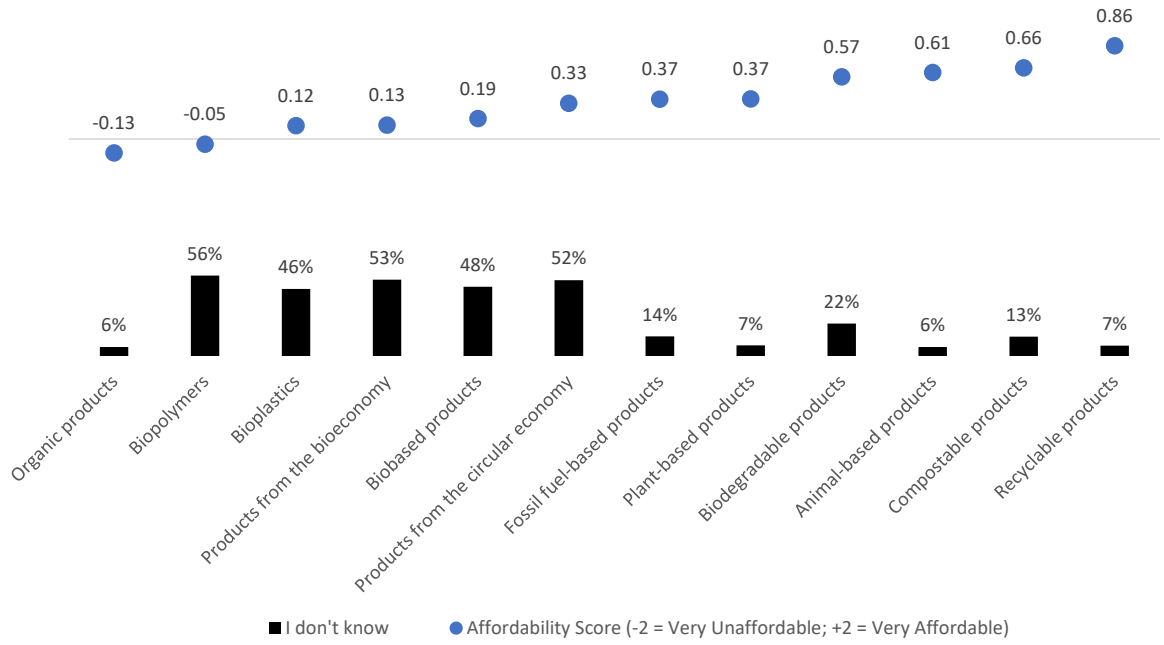

Figure 3.2.3 Are the Following Products Unaffordable or Affordable?

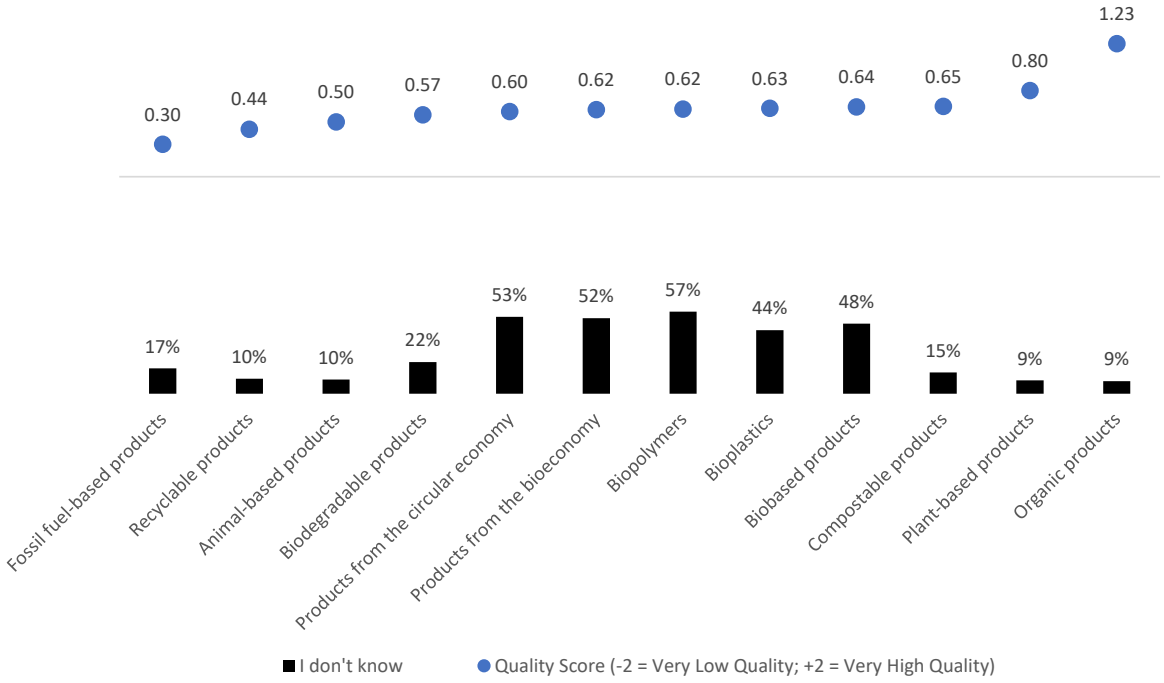

Figure 3.2.4 Are the Following Products Low or High Quality?

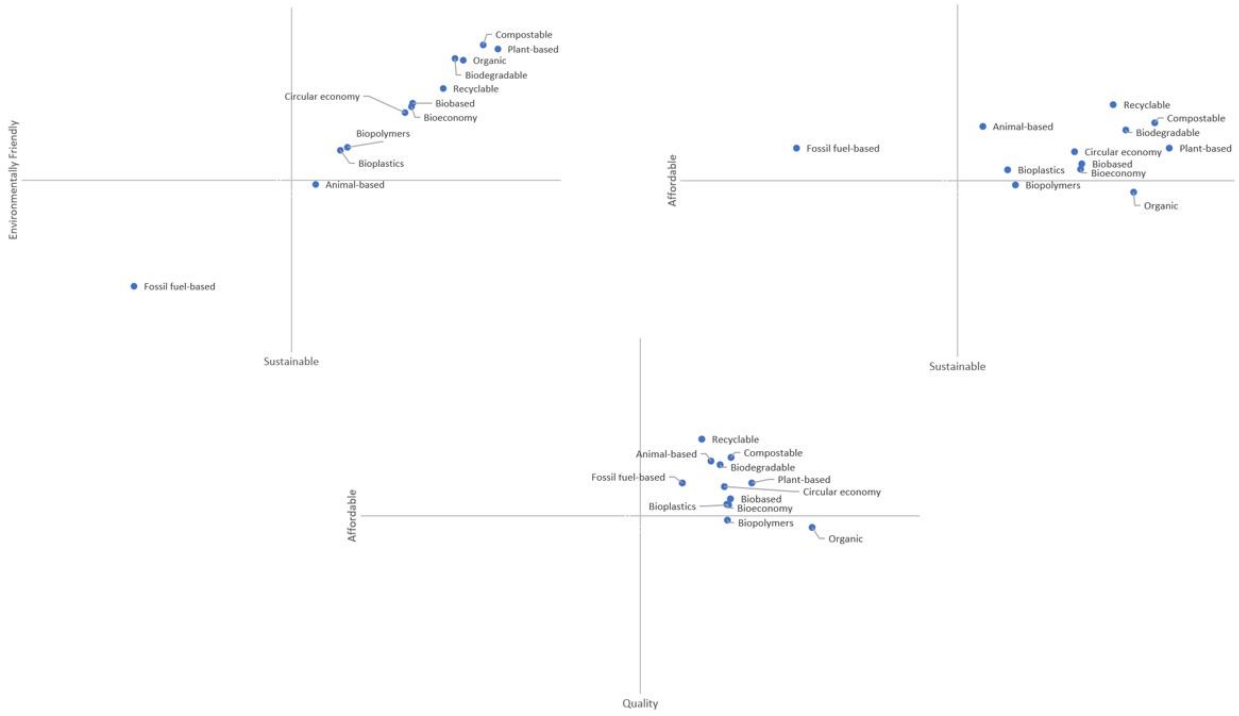

Figure 3.2.5 Relationship between Perceptions of Sustainability, Environmental Friendliness, Affordability, and Quality

To explore inter-relationships between sustainability, environmental friendliness, affordability, and quality, figure 3.2.5 plots average scores for each of the 12 items along two dimensions. As previously indicated, the correlation between perceptions of sustainability and environmentally friendliness is 0.99, as indicated by scores on these two concepts following a nearly perfectly linear relationship (see upper left panel of figure 3.2.5). By contrast, there is only a weak relationship between perceptions of sustainability and affordability (correlation of 0.10, see upper right panel of figure 3.2.5). For example, whereas organic is viewed high on sustainability, it is viewed as low in affordability; by contrast, recyclable products are viewed as relatively high in both dimensions. As expected, there is a negative relationship between perceptions of affordability and quality (correlation of -0.57, see bottom panel in figure 3.2.5). Recyclable products are viewed as relatively affordable and low quality; the opposite is true of organic products.

To further explore respondents' perceptions of biobased and related terms, they were asked to complete a "pile sorting" exercise (see figure 2.2). By exploring how often respondents group terms together, it is possible to construct perceptual maps such as that in figure 3.2.6. The figure shows that in 2-dimensional space, respondents tend to perceive organic and plant-based products as highly similar. Recyclable, biodegradable, and compostable products are also viewed similarly to each other and not too dissimilar from the organic/plant-based clustering. Biobased, bioeconomy, bioplastic, and biopolymer are viewed similarly to one another; they are similar to the organic/plant-based grouping on the vertical axis, but very different on the horizontal axis. The most distinct product, viewed most dissimilarly from all other terms, particularly in the vertical dimension, is fossil-fuel based. Animal-based products and products from the circular economy also do not group well with other concepts, although they are dissimilar from each other, particularly along the horizontal dimension. Comparing figure 3.2.6 to figure 3.2.1 suggests the vertical axis is likely related to perceptions of sustainability; the horizontal axis is harder to interpret but may relate to perceptions of level of subjective knowledge.

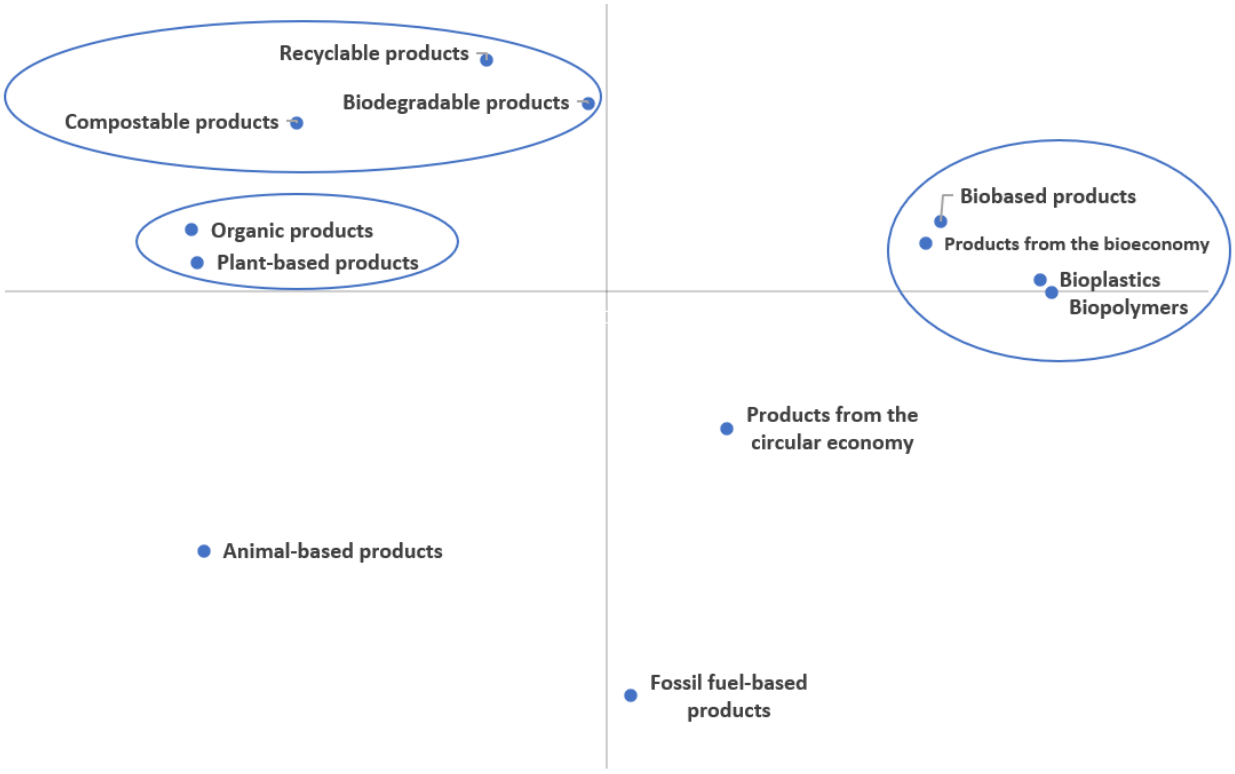

Figure 3.2.6 Two-Dimensional Perceptual Map of Similarity and Differences of Bio-Based Related Terms Determined through Multidimensional Scaling Applied to Pile Sorting Data

In addition to the perceptual map created by use of ordinal multidimensional scaling, perceived similarity among these terms can also be explored via hierarchical cluster analysis. Figure 3.2.7 shows a dendrogram associated with the cluster analysis. The results are broadly similar to those in figure 3.2.6, but provides additional insights into the groupings, with the horizontal distance of the lines providing an indication of the similarity or dissimilarity of terms with a group. Again, organic and plant-based are viewed as highly similar; these terms further relate to a cluster of recyclable, biodegradable, and compostable, with the latter two of these terms being more closely related to each other than with recyclable. Biopolymers and bioplastics are viewed as highly similar terms, and group together with the terms biobased and bioeconomy, ultimately clustering with the more dissimilar term, circular economy.

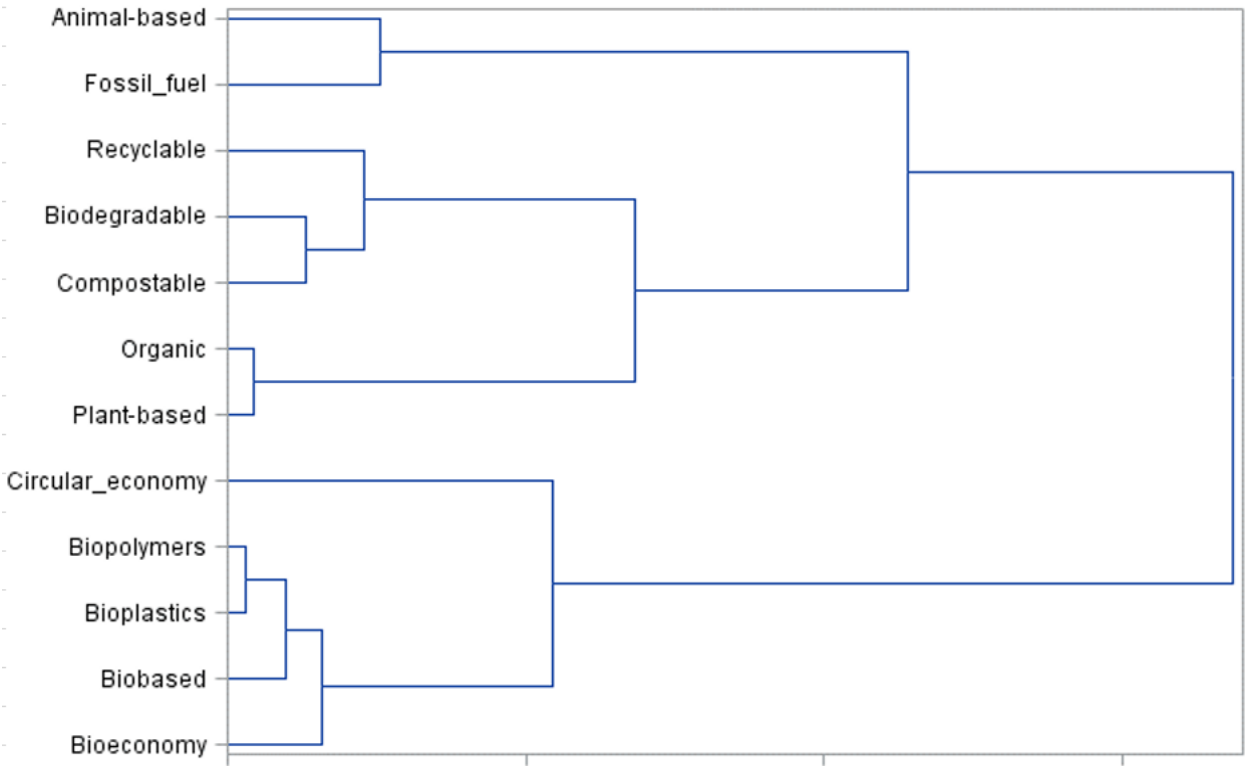

Figure 3.2.7 Dendrogram from Hierarchical Cluster Analysis of Similarity of Bio-Based Related Terms Determined from Pile Sorting Data

3.3 Preferences and Impacts of Information

Figure 3.3.1 illustrates level of support and opposition to a hypothetical policy that would require disclosures of whether a product is recyclable, compostable, biodegradable, or biobased. As the figure shows, there are high levels of support for each of these policies, particularly for recyclable, compostable, or biodegradable, for which 60% or more of respondents say they strongly support. There are strong associations between policy support and political ideology and partisanship. For example, the mandatory disclosure policy on compostable products is strongly supported by 70% of Democrats but only 40% of Republicans. However, 61% of Republicans either strongly support or somewhat support this policy and only about 4% strongly or somewhat oppose.

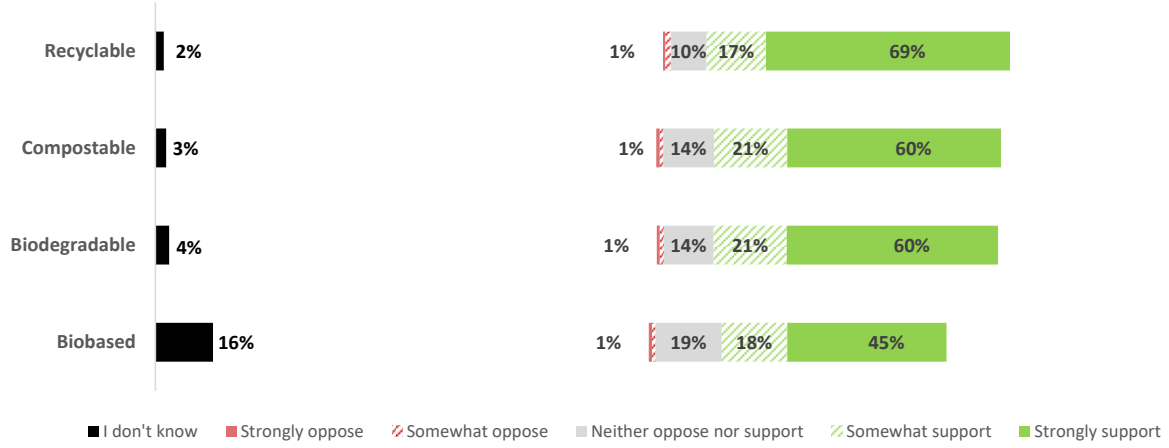

Figure 3.3.1 Do You Oppose or Support a Federal Policy That Would Require that a Disclosure or Definition be Provided When a Product is Labeled as Having the Following Characteristic or Attribute?

In the penultimate section of the survey, respondents participated in simulated shopping scenarios in which they were asked to choose between take-away meals at three restaurants that differed in terms of the price of the meal and the packaging. The packaging had claims labels related to biobased, bioplastic, biodegradable, recyclable, plant-based, and/or compostable (see figure 2.3). Each respondent completed 8 such simulated shopping choices, and these choice data were used to estimate preferences for each label. Results of a likelihood ratio test indicate that preferences were significantly different ($p<0.01$) when definitional information was provided versus when it was absent, and as such, results are presented separately for each information treatment.

Figure 3.3.2 shows the estimated willingness-to-pay premium ($/meal) associated with a restaurant adding a single label/claim vs. no other labels/claims being present. Willingness-to-pay premiums were highest for the compostable claim. Without definitions provided, willingness-to-pay for a take-away meal with compostable packaging was $2.73 higher than when no claims were made. This value premium increased to $3.42 when the definition of compostable was provided. Willingness-to-pay for plant-based packaging was next highest at $1.56/meal without definitions and $0.48 with definitions. In this case, providing the definition of plant-based resulted in a significant reduction in willingness-to-pay for this label claim. Information also dramatically reduced the willingness-to-pay for biodegradable label/claim, turning a positive willingness-to-pay into a discount. Respondents, on average, require a discount to choose a take-away meal that has a biobased or bioplastic claim relative to no claim being made. However, providing definitional information substantively reduced the required discount for bioplastic claims. That is, a bioplastic claim became more acceptable when individuals were provided a definition of the term.

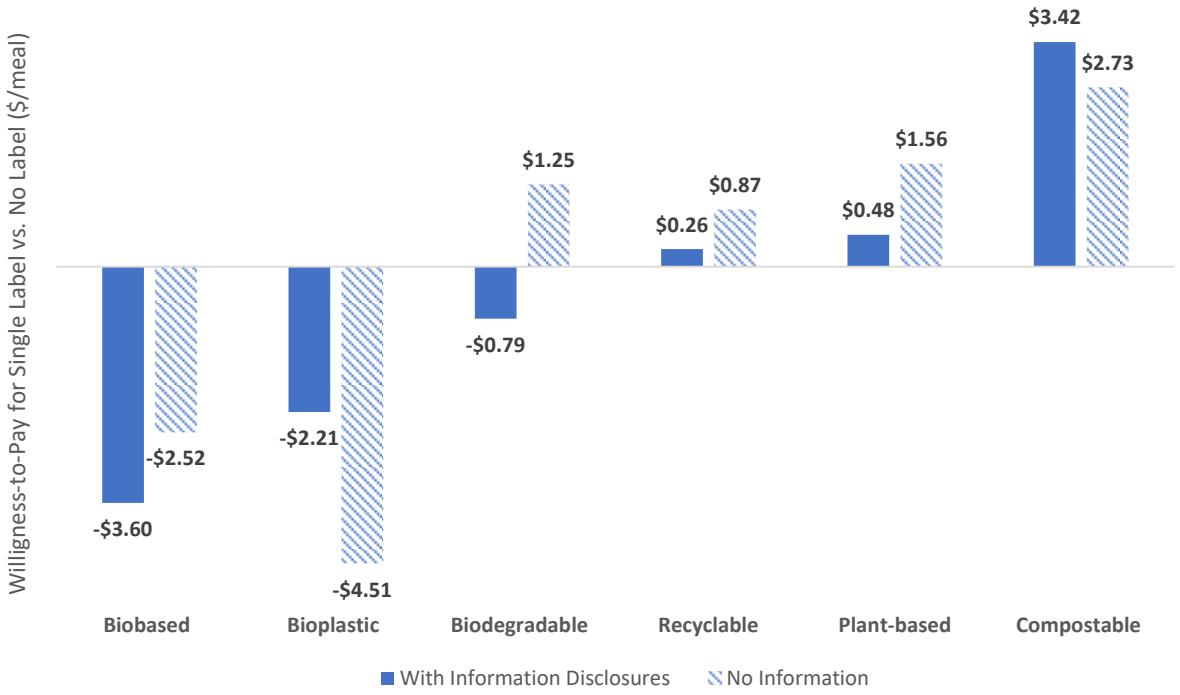

Figure 3.3.2 Willingness-to-Pay for Take-Away Meal with Different Packaging; Value of Single Claim/Label vs. No Claim/Label ($/meal) With and Without Definition Disclosures

The data in figure 3.3.2 shows willingness-to-pay premiums/discounts when each label is considered in isolation; however, multiple labels often appear concurrently and the joint value of multiple labels may be higher or lower relative to what would be expected by simply summing the amounts in figure 3.3.2.

Table 3.3.1 shows the additional premium or discount (above and beyond what would be expected from summing two label values from figure 3.3.2) when multiple labels appear concurrently. For example, when definitional information is provided, table 3.3.1 shows the willingness-to-pay for a take-away meal with both a plant-based and biobased label is $0.99/meal higher than would be implied by adding the two individual label effects from figure 3.3.2. Stated differently, willingness-to-pay for a take-away meal that has both a plant-based and biobased label (and no other labels) is $0.99 + $0.48 - $3.60 = -$2.13 lower than a take-away meal with no claims/labels. Because the additive (or interaction) term is positive in this case, it means plant-based and biobased are complements when definitional information is provided. However, the opposite is true when information is not provided.

Table 3.3.1 also shows that a compostable claim is a partial substitute for a bioplastic or biodegradable claim regardless of whether definitional information is provided, meaning consumers tend to view these terms conveying similar and overlapping benefits. The same is true of compostable and recyclable claims. For example, when definitions are provided and compostable and recyclable claims appear jointly, willingness-to-pay is $1.73 lower than would be implied by the simple sum of values from figure 3.3.2. When these two labels are jointly present with definitions, willingness-to-pay for a joint compostable, recyclable product is -$1.73 + 3.42 + $0.26 = $1.95 higher than a take-away meal making no claims. The interaction terms in table 3.3.1 are, on average, higher in absolute value when definitions are not provided. This implies that information tends to cause individuals to view each label more on its own merits than as signaling additional information about other labels/claim.

Table 3.3.1 Additional Premium or Discount when Labels/Claims Jointly Appear on Packaging

	Plant-based	**Biobased**	**Bioplastic**	**Compost-able**	**Biodegrad-able**
With Definitions					
Biobased	$0.99				
Bioplastic	$0.80	$1.50			
Compostable	$1.81	$0.15	-$0.69		
Biodegradable	-$0.19	$1.22	$0.11	-$0.78	
Recyclable	$0.02	$1.04	$0.31	-$1.73	$1.29
No Definitions					
Biobased	-$0.96				
Bioplastic	$1.91	$1.24			
Compostable	$1.69	$0.12	-$1.05		
Biodegradable	-$1.94	-$0.06	$0.79	-$0.38	
Recyclable	$0.46	$1.19	$0.46	-$2.10	-$0.58

Rather than reporting results in terms of willingness-to-pay, outcomes can be interpreted in terms of impacts of probability of selection. Because of the impact of the interaction effects, we consider two calculations: one is the change in the probability of purchase when a label is added to packaging that already contains all other labels and another is the change in probability of purchase when a label is added to packaging that contains no other labels. The wider the difference between these two calculations (demarcated by the circle and x in the following figures), the greater the impact of interaction effects.

Figure 3.3.3 shows the change in odds of purchasing a meal when a label is added in the presence of information disclosures. Adding a plant-based label causes the highest positive change in odds when all other labels are already present, but adding a compostable label causes the largest change in purchase probability when no other labels are present. The labels most unlikely to have a positive impact on purchase probability are biobased and bioplastic as they show a change in odds of purchase below one (meaning people are less likely to choose products with these labels once they are added). For the term bioplastic, this is true regardless of the presence/absence of other labels; for biobased, adding the term when others are already present increases the odds of buying the meal, but adding the term when no other labels are present reduces the odds of buying the meal (as indicated by an odds calculation below one).

Figure 3.3.4 shows the same calculations but when definitions are not provided. The pattern of results, in terms of relative importance of each of the six labels is broadly consistent with the results in figure 3.3.3. Namely, adding plant-based and compostable labels tends to have the highest positive impact on odds of purchase, whereas adding biobased and bioplastic labels tends to have the most detrimental impacts on odds of purchase. Both figures also show that plant-based label tends to have the largest positive impact on purchase odds when it appears alongside other labels, whereas the compostable label has the largest positive impact when it appears alone. This is a result of the preference interactions shown in table 3.3.1. The value of compostable label falls when it appears alongside labels like recyclable, biodegradable, and bioplastic, as these labels are substitutes for compostable.

Contrasting the purchase odds in figures 3.3.3 and 3.3.4 yields insights into the effect of information. When packaging already contains many competing claims/labels (the calculations demarcated by the circles in the figures), provision of information disclosures increases the value of adding a new biobased claim in all instances. For example, the odds of buying plant-based increases from 1.87 to 2.49 when information is provided; likewise, the odds of buying bioplastic increases the from 0.76 to 0.96 when information is provided. However, when adding a single label/claim in the absence of any others (the calculations demarcated by the Xs in the figures), definitional information reduces likelihood of purchase for four terms (biodegradable, recyclable, plant-based, and biobased) while increasing it for two terms (bioplastic and compostable).

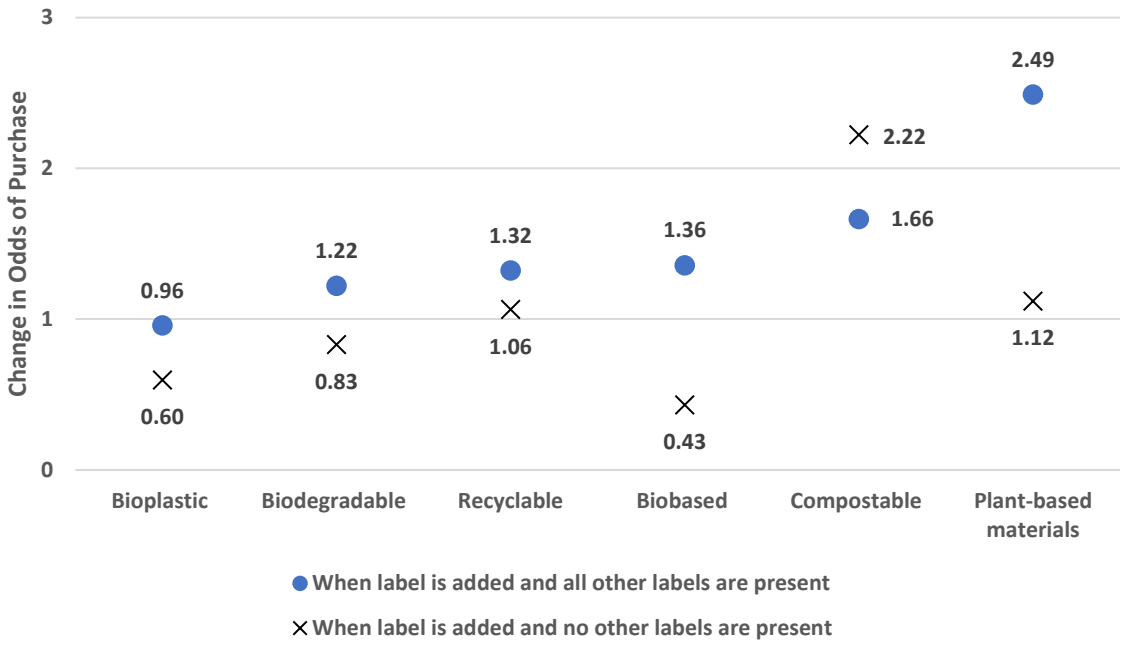

Figure 3.3.3 Change in Odds of Choosing Packaged Products when Definitions are Provided

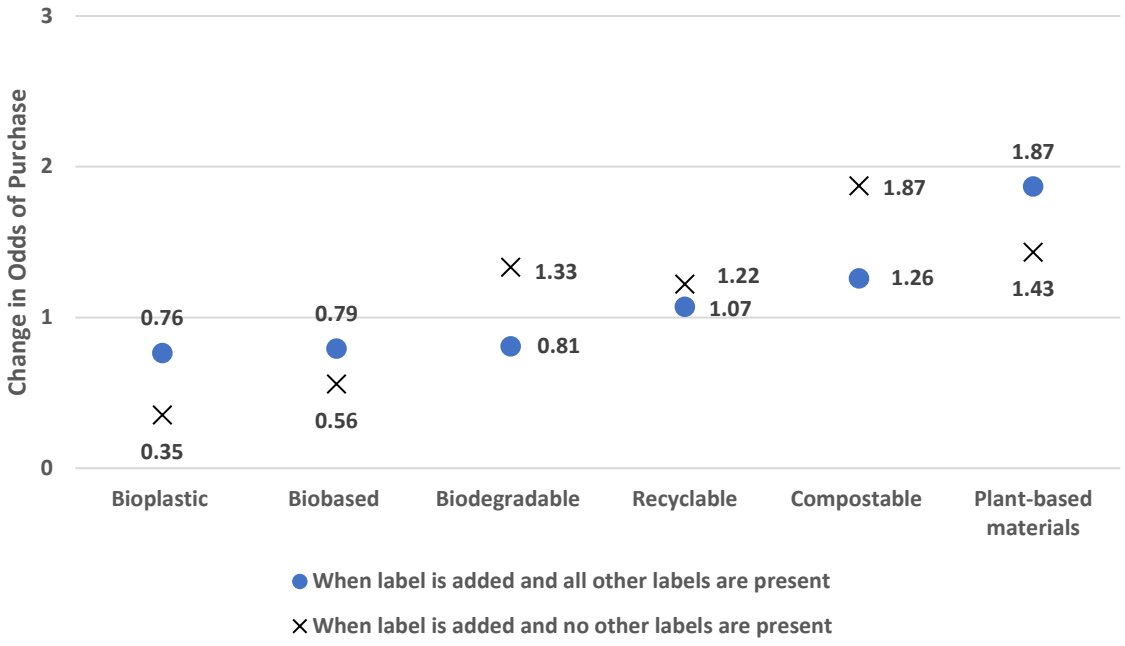

Figure 3.3.4 Change in Odds of Choosing Packaged Products when Definitions are Not Provided

4. Conclusions

This research sought to determine the public's knowledge, beliefs, and preferences for 10 terms related to the bioeconomy: biobased, biodegradable, bioeconomy, bioplastics, biopolymer, circular economy, compostable, organic, plant-based, and recyclable. To explore these issues, a nationwide survey of almost 1,500 U.S. individuals was conducted in early December 2022.

Results reveal low levels of subjective knowledge for terms like biobased, bioeconomy, bioplastics, biopolymer, and circular economy. Individuals were likely to indicate they had never heard of the terms or did not know what they meant, and they commonly selected "I don't know" when asked specific knowledge questions about these terms. By contrast, individuals tended to indicate greater familiarity with terms like recyclable, organic, plant-based, biodegradable, and compostable. Despite the higher subjective knowledge of these terms, objective knowledge levels were low for most people. When asked true/false and definitional questions, less than 1% of the population scored an "A" (i.e., fewer than 1% got 90% or more of the questions correct). In fact, 57% of respondents got as many questions wrong as right. The highest average objective knowledge scores were observed for white, non-Hispanic, middle-aged, and higher educated individuals.

That the strongest predictor of objective knowledge was the presence of a bachelors, and especially, a graduate degree suggests a role for education in helping the public understand these terms. Nevertheless, educational campaigns are costly, and just because more highly educated individuals know more about biobased terms, does not necessarily imply providing information to less educated individuals, in the context of daily life, will substantively improve their knowledge, particularly if different types of people select into different education levels.

Despite the fact that educational campaigns are unlikely to be a silver bullet, results show strong public support for policies on information disclosures related to compostable, recyclable, or biodegradable. Moreover, simulated shopping scenarios show that the presence of information disclosures at the time of purchase can significantly impact choice and willingness-to-pay.

This research also studied individuals' beliefs and perceptions of terms related to the bio-economy. Perceptually, respondents tend to view terms like organic and plant-based as being highly similar and related to another grouping of perceptually similar terms: biodegradable, compostable, and recyclable. Perceptually, respondents view all other terms with a "bio" prefix similarly: biobased, biopolymer, bioplastic, bioeconomy. Despite respondents viewing these groups of terms similarly, they can imply very different things. For example, despite respondents viewing plant-based an organic as being highly similar terms, an organic product does not have to be plant-based and a plant-based product does not have to be organic. Such findings suggest potential for consumers to draw inaccurate inferences and potentially be misled about underlying properties of products. Creating and providing uniform definitions of these terms and harmonizing definitions across products and regulatory jurisdictions may reduce the odds of these adverse outcomes for consumers.

Overall, the aim of this research was to contribute to the development of more sustainable and environmentally responsible consumption patterns by helping remove confusion created by divergent state and local governments policies and labeling practices, remove barriers for businesses aiming to accurate communicate about their products, and ultimately promote growth of the bioproducts industry and the broader bioeconomy.

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