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Consumers' willingness to pay for second-generation ethanol in Brazil

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ABSTRACT

Although Brazil has great potential to commercially produce second-generation ethanol (E2G), almost all ethanol currently produced in Brazil is first-generation ethanol (E1G). Considering that Brazil does not have a federal mandate requiring increased deployment of E2G to meet their biofuel blending requirement, the extent to which a market for E2G emerges will depend in part on the potential premium consumers are willing to pay for E2G. This work summarizes a consumer survey about their willingness to pay (WTP) for E2G. The survey was conducted in 24 Brazilian states to assess how WTP for E2G is affected by respondents' driving habits, knowledge about biofuels, acceptance of relevant biofuel policies, and demographic characteristics. Using dichotomous-choice contingent valuation, we found that, on average, Brazilian consumers are willing to pay an 8.5 percent premium for gasoline blended with E2G. We estimate that an 8.5 percent price premium is enough to use as much as 62.5 percent of E2G in the currently mandated E27 blended fuel (E27) without the need of government support/subsidies. Results also suggested that consumers more informed about biofuels and with higher income are more likely to pay a premium for E2G. Informing consumers about E2G thus would enhance likelihood of adoption.

1. Introduction

Global concerns about climate change and oil prices have increased the interest in biofuels (Basso, 2015). Brazil has an internationally recognized ethanol industry (Le Bouthillier et al., 2016) that has helped the country achieve a strategic position to meet the environmental targets established by the country at the United Nations Climate Change Conference (2015 UNFCCC). Practically all ethanol in Brazil is produced from sugarcane, which reduces greenhouse gas (GHG) emissions by 78 percent compared to gasoline (Delgado et al., 2017). The production of second-generation ethanol (E2G) from cellulosic feedstocks such as bagasse is even more efficient, reducing GHG by 86 percent relative to gasoline (Delgado et al., 2017). Currently most bagasse in Brazil is used to produce steam for ethanol and sugar production, as well as to power turbines (Joppert et al., 2017). Alternatively, converting bagasse to E2G may be an opportunity to diversify its use and increase its value-added potential.

While sugarcane ethanol is shown to be technically and economically superior to all other crops currently in use, "it is widely thought that this advantage will be undermined once second-generation ligno-cellulose technology becomes commercially available" (Borras et al., 2013, p. 182). Even though biofuels, i.e., ethanol and biodiesel, contribute to minimizing fossil fuel consumption, the sustainability of the first-generation ethanol (E1G) industry is questionable due to the potential stress its production places on food commodities, and the environmental impact caused by land use change (LUC) and deforestation (Halder et al., 2019; Mat Aron et al., 2020). Although the use of sugarcane to produce ethanol in Brazil is not perceived as a threat to the world food situation due to sugar not being a staple food like corn (Carpio and Souza, 2019), there are concerns about direct and indirect LUC associated with the production of first-generation ethanol (E1G) in the country. A significant portion of Brazil's GHG emissions comes from LUC and deforestation, which have been associated with the expansion of sugarcane farming (Jusys, 2017). In this context, studies have suggested that the impact of biofuel production can be reduced by promoting feedstocks that do not compete with food or feed crops for land, such as use of residues like sugarcane bagasse, straw, and tips (Plassmann, 2018).

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Despite Brazil's long history of public policies supporting the E1G industry, the same has not happened with the E2G industry. For instance, even though Brazil established a mandatory blending requirement policy (E27) in March 2015, the country has not created mechanisms to increase the production of E2G. Hence, almost all ethanol produced in Brazil is E1G because the country does not have a federal mandate requiring increased blending of E2G. While Brazil's E1G production for 2019 is estimated at 34.45 billion liters, E2G production is estimated at only 45 million liters (Barros, 2019) or 0.1% of total ethanol production. In this context, the extent to which a market for cellulosic ethanol emerges in Brazil depends largely on how much consumers in the country prefer E2G relative to gasoline.

The objective of this study is to examine Brazilian consumers' WTP for E2G to find answers about whether consumers are willing to pay a premium (discount), how large the premium (discount) may be, and how information about E2G and the socioeconomic characteristics of consumers affect their WTP for E2G. These issues are important for two reasons. First, the investigation of whether an information treatment produces a significant effect on consumers' WTP for E2G in Brazil can help design a marketing strategy for E2G in the country (Li and McCluskey, 2017). Second, the results could provide rationale for mandating the use of E2G and suggest a method for message framing to inform consumers about their fuel choices (Van de Velde et al., 2010).

2. Consumers' willingness to pay for biofuels

Several studies have been conducted worldwide to investigate consumer attitudes and their WTP for biofuels and other renewable energies. While some scholars conducting WTP studies have indicated that consumers show a preference for solar, wind or generic renewable energy sources (i.e., no indication of specific source) over electricity generated from biomass (e.g., crop and forestry derived energy, biogas, and biodegradable waste) (Ma et al., 2015), others have found evidence that consumers are WTP a premium for biofuels in general (Giraldo et al., 2010; Solomon and Johnson, 2009).

As E2G further develops, studies focusing on public support for second generation biofuels have recently become more common, and the findings point to a positive view of E2G by consumers as expressed in their WTP a premium for it (Mamadzhanov et al., 2019). For instance, Baral and Rabotyagov (2017) analyzed the public's WTP for wood-based cellulosic biofuels and the factors that influence their WTP decisions in the U.S. Pacific Northwest and concluded that almost one-fifth (18.8%) of the respondents were willing to pay a 6.4 percent price premium over the market price of gasoline. In a similar study, Farrow et al. (2011) found that consumers in New England were WTP a 1 to 4 percent premium for wood-based ethanol relative to the price of regular fuel. Li and McCluskey (2017) investigated the consumer response toward E2G in three major U.S. cities: Portland, Minneapolis, and Boston, and concluded that the average respondent was willing to pay an 11 percent premium for E2G compared to conventional fuel.

In Canada, Dragojlovic and Einsiedel (2015) analyzed consumer acceptance of advanced biofuels in comparison with conventional biofuels. The authors tested for the effect of two anti-biofuels arguments on Canadians' support for policies meant to encourage the production of biofuels. Results suggested that support for biofuels policies was reduced when respondents were exposed to an argument about the potential impact of biofuels production on food prices and when they were told that the use of woody biomass as a feedstock for the production of cellulosic biofuels might lead to an increase in commercial logging. In both cases, however, support was reduced only among respondents who did not perceive climate change to pose a significant risk. Other variables that have been found to be statistically significant predictors of WTP decisions in other studies include the offered bid, price, knowledge about biofuels, age, and religious affiliation of respondents (Baral and Rabotyagov, 2017; Lanzini et al., 2016).

Thus, the literature on consumer preferences for second generation biofuels points to two general features that are particularly relevant to this study: 1) E2G seem to be preferred by consumers relative to conventional fossil fuel, and 2) respondents' perception about the severity of the threat posed by climate change is a key predictor of their attitudes toward biofuel (Dragojlovic and Einsiedel, 2015).

The few studies conducted in Brazil to assess consumers' perceptions about various forms of renewable energy find a positive attitude (Moreira et al., 2013; Souza and Pompermayer, 2015). However, there are no studies that have assessed consumers' WTP. To our knowledge, this study is the first assessment of Brazilian consumers' WTP for E2G. In addition, researchers have long pointed out the need for energy policy research in Brazil. In a critique of the current state of ethanol policy in Brazil, Corrêa et al. (2017) argued that the field of public policy no longer contributes significantly to the understanding and development of energy policy in Brazil, including ethanol. The authors maintained that the effectiveness of public policies that provided incentives to the sugar-ethanol sector must be assessed, "including the model of incentives and the consequences to the society" (Corrêa et al., 2017, p. 19).

3. Methodology

We conducted a contingent valuation (CV) study to estimate consumers' WTP for E2G. We applied a double-bounded dichotomous choice model asking respondents about their WTP for E2G using two rounds of bids. Each respondent was asked if they were willing to purchase E2G at a randomly assigned price relative to standard E27 gasoline. For the first round of bidding, a respondent would respond to a randomly chosen alternative price level in comparison to a reference price for standard E27 gasoline (R$4.08). The nine choices presented included the same reference price or prices with premia or discounts of ±5%, ±10%, ±15%, and ±20% which they would be willing or unwilling to pay. If their initial bid involved a premium/discount that they accepted over the reference price, the second round elicited whether they would be willing to double their premium/accept half the discount, respectively. Similarly, if they rejected their initial bid premium/discount, the second bid choice reflected a lesser premium/greater discount, respectively. This choice set is presented in Fig. 1. The standard E27 price is followed by nine initial bid choices that were randomly assigned to a respondent for the first bid and a second round of bid options pending their willingness or unwillingness to pay the first bid. The wording used for a scenario where the respondent was asked to respond to a discount relative to the reference price of E27 gasoline is provided in Appendix A.

Following Lopez-Feldman (2012), the responses to the CV questions produce four possible outcomes in a dichotomous question with follow-up, where the first bid amount is t^1, the second bid amount is t^2, and WTP is the respondent's WTP for E2G:

(1) The respondent is willing to buy E2G at the initial bid, but not willing to buy it at the second bid ("yes" to the first question, "no" to the second question). In this case, we can infer that $t^1 \leq \text{WTP} \leq t^2$.
(2) The respondent is willing to buy E2G at both the initial bid and the premium price ("yes" to both questions). In this case, we can infer that $t^2 \leq \text{WTP} < \infty$.
(3) The respondent is not willing to purchase E2G at the initial bid, but is willing to buy it at the second bid ("no" to the first question, "yes" to the second question). In this case, we can infer that $t^2 \leq \text{WTP} < t^1$.
(4) The respondent is not willing to purchase E2G at the initial or the second bid price ("no" to both bids). In this case, we can infer that $0 < \text{WTP} < t^2$.

The individual WTP outcome is based on the random utility model where the respondent maximizes utility by choosing to purchase a

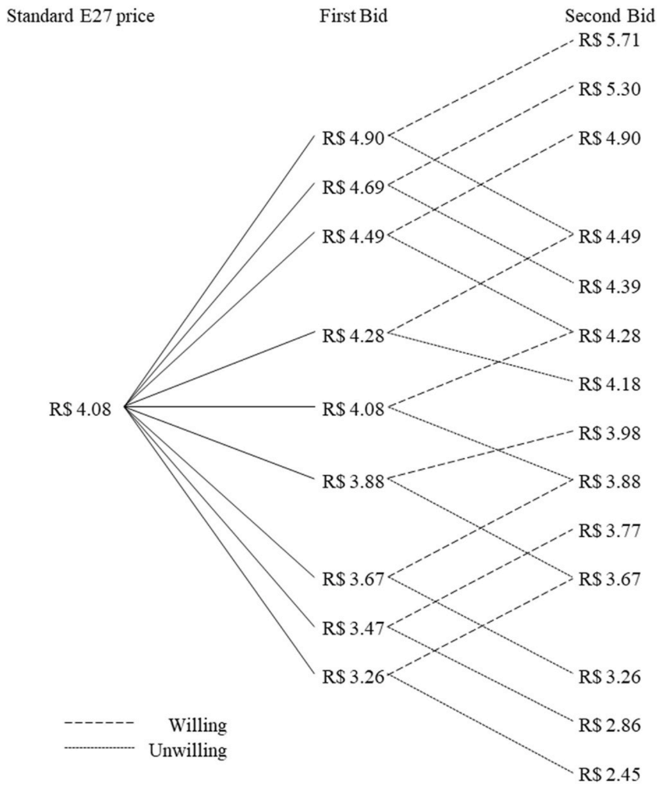

Fig. 1. Price tree showcasing price premium and discount choices for respondents presented with two rounds of bidding choices for E2G relative to conventional E27 blends.

product at the associated bid amount if the utility derived from this good is higher than from refusing the bid and foregoing the product (Mamadzhanov et al., 2019). Under the assumption that $WTP_i(z_i, u_i) = z_i^{'}\beta + u_i$ and $u_i \sim N(0, \sigma^2)$, where z_i is a vector of explanatory variables, β is a vector of parameters, and u_i is an error term, the probability of each of the four outcomes described above is estimated as follows:

$$\Pr(y=j)\left\{\begin{array}{l} \Phi\left(z_i^{'}\frac{\beta}{\sigma}-\frac{t^1}{\sigma}\right)-\Phi\left(z_i^{'}\frac{\beta}{\sigma}-\frac{t^2}{\sigma}\right) \\ \Phi\left(z_i^{'}\frac{\beta}{\sigma}-\frac{t^2}{\sigma}\right) \\ \Phi\left(z_i^{'}\frac{\beta}{\sigma}-\frac{t^2}{\sigma}\right)-\Phi\left(z_i^{'}\frac{\beta}{\sigma}-\frac{t^1}{\sigma}\right) \\ 1-\Phi\left(z_i^{'}\frac{\beta}{\sigma}-\frac{t^2}{\sigma}\right) \end{array}\right\} for\ j=\left\{\begin{array}{c}1\\2\\3\\4\end{array}\right\} \tag{1}$$

where Φ is a cumulative distribution of the normal function characterizing the random components of utility and j represents the four possible choices outlined above.

We maximize the following equation to estimate the unknown parameters β and σ:

$$\begin{aligned} \ln L = \sum_{i=1}^{n}\Bigg\{ & d_i^1 \ln\left(\Phi\left(z_i^{'}\frac{\beta}{\sigma}-\frac{t^1}{\sigma}\right)-\Phi\left(z_i^{'}\frac{\beta}{\sigma}-\frac{t^2}{\sigma}\right)\right)+d_i^2 \ln\left(\Phi\left(z_i^{'}\frac{\beta}{\sigma}-\frac{t^2}{\sigma}\right)\right) \\ & + d_i^3 \ln\left(\Phi\left(z_i^{'}\frac{\beta}{\sigma}-\frac{t^2}{\sigma}\right)-\Phi\left(z_i^{'}\frac{\beta}{\sigma}-\frac{t^1}{\sigma}\right)\right)+d_i^4 \ln\left(1-\Phi\left(z_i^{'}\frac{\beta}{\sigma}-\frac{t^2}{\sigma}\right)\right)\Bigg\} \end{aligned} \tag{2}$$

where d_i^j is the indicator for each individual i.

Considering that the information about E2G in Brazil might be scarce among consumers, we implemented an information treatment about E2G. Half of the sample was presented a scientifically based, two-tailed information (both benefits and drawbacks) about E2G, while the other half of the respondents was not presented with the script (Appendix B).

3.1. Data

A total of 538 surveys were distributed to respondents in Brazil in April of 2020 using the online market research firm Dynata. A sample of Brazilian respondents who drive a vehicle was randomly drawn from Dynata's consumer panel. Respondents who finished the online survey received a modest participation reward per Dynata's incentive system. The survey was comprised of three main parts. First, respondents were divided into two approximately equal groups. One group was prompted with the information script before the CV survey, while the other group did not see the information script. All participants were presented with a cheap-talk script to control for hypothetical bias by asking them to provide honest responses as if they were actively biding for these products in the market (Cummings and Taylor, 1999; Loureiro et al., 2006). We used screening questions to select only respondents who drive a vehicle, and respondents who use mostly hydrated ethanol (E100) and gasoline (E27) as fuel (instead of other fuels, such as diesel).

Research has shown that the use of the average market price of fuels as the initial bid can potentially mitigate starting point bias in new technology valuation (Huffman and McCluskey, 2017; Mamadzhanov et al., 2019), which is a bias that occurs when respondents anchor their valuation on the first bid proposed to them. In this study, we selected the average retail price of regular gasoline E27 in Sao Paulo from September 03, 2020 to 03/30/2020 as the reference price for the estimation of the initial bid, which was R$4.08/L (US$0.98/L) (ANP, 2020). Nine price levels were selected for the first price bound, and 14 price levels were selected for the second bound (Fig. 1).

Following the CV survey, participants were asked about their knowledge of biofuels, socioeconomic condition, and perceived consumer effectiveness (PCE). The term PCE was coined by Kinnear et al. (1974) and defined as the degree of belief that an individual consumer can be effective in pollution abatement. Roberts (1996) offers a similar definition for PCE as a construct designed to measure the respondent's judgment regarding their ability to impact or affect environmental resource problems. Researchers have suggested that individuals become more concerned about the environment when they feel that they can individually influence it (Higueras-Castillo et al., 2019; Skipper et al., 2009). Recently, PCE has been applied by researchers to explain the motivations for environmental behavior and attitudes (Ghvanidze et al., 2016). Following Roberts (1996), we employed the four questions to calculate the PCE total scaled score as the sum of the responses to the four PCE questions that could from 4 to 12. The higher the PCE total scaled score, the higher the respondent's confidence in their ability to influence the environmental condition with their purchasing decisions.

4. Results

4.1. Descriptive statistics

The demographic characteristics of the respondents for the overall sample are summarized in Table 1. Given the lack of statistics for a comparable population (namely.

Brazilians that drive a gasoline/ethanol car), and acknowledging that sample representativeness is often a concern in all surveys (Mamadzhanov et al., 2019), we compare the survey data to national statistics for general reference. In the overall sample, the average age of respondents was approximately 34 years old, which is similar to the average age in Brazil (32.6 years).

The majority of respondents belong to an active age group of the population, more specifically between 26 and 39 years old. The portion of male respondents in the sample was 61 percent, compared to 48.2 percent in the general population (Instituto Brasileiro de Geografia e Estatística, 2019), and 59 percent of licensed drivers in Brazil

Table 1
Summary statistics for demographic variables for the survey respondent sample.

Variable	Category	N	Sample	Population %
Gender	Female	209	39%	51.8%
	Male	329	61%	48.2%
Age	18–25 years	154	28%	11%
	26–39 years	233	43%	23%
	40–60 years	142	26%	26%
	Over 61 year	9	2%	16%
Education level	Bachelors or Graduate	168	31%	17%
	High school or technical school	297	55%	31%
	Elementary school or less	73	14%	52%
Income[a]	Less than R$2000	212	40%	70%
	R$2000-R$3000	124	23%	10%
	R$3000-R$5000	97	18%	10%
	R$5000-R$10,000	68	12%	5%
	More than R$10,000	37	7%	5%
Region	Center-West[b]	30	6%	8%
	North[c]	25	5%	9%
	Northeast[d]	101	19%	27%
	South[e]	84	15%	14%
	Southeast[f]	298	55%	42%
Political ideology on social issues	Conservative	165	31%	
	Center	167	31%	
	Liberal	206	38%	
Political ideology on economic issues	Conservative	168	32%	
	Center	185	34%	
	Liberal	185	34%	
Political Position	Right	170	32%	
	Center	267	50%	
	Left	101	18%	

[a] Per capita income was disaggregated into low (<R$2000 a month), middle (between R$2000 and R$5000 a month), and high income (>R$5000 a month) dummy variables based on the class criteria defined by the Brazilian Institute of Geography and Statistics (IBGE) (Fundação Getulio Vargas, 2020).
[b] Includes the states of Goiás, Mato Grosso do Sul, Mato Grosso, and the Federal District.
[c] Includes the states of Acre, Amapá, Amazonas, Pará, Rondônia, Roraima, Tocantins.
[d] Includes the states of Alagoas, Bahia, Ceará, Maranhão, Paraíba,Pernambuco, Piauí, Rio Grande do Norte, Sergipe.
[e] Includes the states of Paraná, Rio Grande do Sul, Santa Catarina.
[f] Includes the states of Espírito Santo, Minas Gerais, Rio de Janeiro, São Paulo.

(Ministério da Infraestrutura, 2019).

Responses came from 24 of the 26 Brazilian states. Fifty five percent of the respondents were from the Southeast region of Brazil. This was expected considering that the region consumed 60 percent of ethanol in Brazil in 2019 (UNICA, 2020). In addition, 15 percent of respondents reported that their region of residence was the South, which reflected the region's share of ethanol fuel consumption in the domestic market in 2019 (13%). The region with the lowest number of respondents was the North region (5%), where ethanol fuel consumption is the lowest in Brazil (3%).

Our sample of respondents had a higher level of education compared to the national average. For example, more than half (55 percent) of the respondents reported having completed high school or technical school and 31 percent had a college degree whereas 31 and 17 percent of the Brazilian population have similar levels of education, respectively (Instituto Brasileiro de Geografia e Estatística, 2018). Moreover, our sample had a higher income level than that of the total population. For instance, forty percent of respondents reported having a monthly per capita income of less than R$2000 (US$374) and 37 percent had a monthly income level of more than R$3000 (US$560). Respectively, this compares to 70 and 20 percent for the entire Brazilian population (Instituto Brasileiro de Geografia e Estatística, 2020). The underrepresentation of low-income households in our sample is expected given that car ownership is the lowest (only 10% of households) in the northern and northeastern regions (Clima e Sociedade, 2020) with the lowest per-capita income in Brazil (Instituto Brasileiro de Geografia e Estatística, 2021). The differences in education and income between our sample and the Brazilian population highlights possible external validity issues. Since data for Brazilians that drive a gasoline/ethanol car are not available we cannot present more relevant information.

Overall, respondents were evenly divided in their self-described ideology on economic issues −− 32 percent identify as conservative, 34 percent as center, and 34 percent as liberal. On social issues, a plurality of respondents declared being liberal (38%). Finally, in terms of political identification, 50 percent of respondents declared being center, 32 percent right-wing, and 18 percent declared themselves left-wing. These statistics are some in what different than found in a recent survey conducted by the Datafolha Institute (2017), according to which 20%, 40%, 40% of the population were center, right-, and left-wing, respectively.

Responses to survey questions regarding driving habits, as well as knowledge and attitudes towards biofuels are summarized in Table 2. Three out of four respondents reported having only one car in the household, and around 30 percent report owning a hybrid car. Four out of five respondents stated that they know about biofuels. The vast majority (95 percent) of the respondents support government promotion of biofuels, primarily in the form of subsidies or tax breaks. Respondents reported driving an average of 234 km (145 miles) each week (SD = 654).

The distribution of bid responses is displayed in Table 3. The majority (70 percent) of the respondents who were offered to buy E2G at a discount said they are willing to buy it, while around half of those who were offered to buy E2G at a premium said they are willing to buy it. Looking at the share of positive responses across all price levels (from −40 percent to +40 percent of the price of regular gasoline), we see a negative but statistically insignificant relationship.

Descriptive statistics for each of the four PCE questions as well as the total scale scores are shown in Table 4. The high mean total scaled score indicates that respondents as a whole have a high confidence in their ability to influence environmental outcomes with their purchasing actions. Looking at the frequency of PCE responses (Fig. 2), we see that 37.5 percent of respondents scored the highest (12) PCE score, and that the frequency of the responses falls below 5 percent for PCE scores below 8. The Cronbach's alpha is somewhat low (Nunnally and Bernstein, 1994; Bland and Altman, 1997) while the item correlations suggest internal consistency (Spector, 1992).

Variables used in the CV model are described in Table 5. The dummy variable Region NNE equals 1 for all respondents that reported living in the North and Northeast regions of Brazil and zero otherwise. Similarly, the variable Region CWSE equals 1 for respondents from the Center West and Southeast regions, and zero otherwise. Finally, the dummy variable Region S equals 1 for residents from the South region and zero otherwise. Respondents' political affiliation variable was scored as 1 if the respondent reported being right-wing and zero otherwise. Following Mamadzhanov et al. (2019), the variable age was coded 1 if respondents were aged 18–40 and zero otherwise. The variable education equals 1 for respondents with completed bachelor's degree or above and zero otherwise. Gender was coded 1 for female and zero for male.

4.2. Contingent valuation model results

Model results[1] are presented in Table 6. Interestingly, we find that the information treatment had no statistically significant impact on consumers' WTP for E2G. Both variables associated with biofuels knowledge (Knowledge and RenovaBio) were statistically significant and positive. Being knowledgeable about biofuels had a statistically significant ($p > 0.05$) coefficient, meaning that WTP for E2G was higher

[1] The model was implemented using the double command in Stata®.

Table 2
Summary statistics for variables related to driving habits and knowledge about biofuels.

Variable	Category	N (%)
Number of vehicles in household	One	413 (77%)
	Two	102 (19%)
	More than 2	21 (4%)
Distance driven per week	Average 234 km	
Household owns a hybrid (flex fuel) car	Yes	155 (29%)
	No	383 (71%)
Main fuel type consumed[a]	Gasoline (E27)	414 (77%)
	100% ethanol (E100)	124 (23%)
Knowledge about biofuels[b]	Yes	433 (81%)
	No	105 (19%)
Government promotion of biofuels instead of gasoline/diesel of biofuels	Yes	506 (94%)
	No	32 (6%)
Type of government incentive[c]	Subsidies/tax breaks	349 (69%)
	Marketing campaign	156 (31%)
Knowledge about RenovaBio[d]	Yes	174 (32%)
	No	364 (68%)
Opinion about RenovaBio among those that know about it	Positive	137 (78%)
	Neutral	35 (21%)
	Negative	2 (1%)
Importance of fuel price	Very important	475 (89%)
	Somewhat important	56 (10%)
	Not important	7 (1%)
Importance of environmental friendliness of fuel	Very important	363 (67%)
	Somewhat important	150 (28%)
	Not important	25 (5%)
Importance of fuel efficiency	Very important	471 (88%)
	Somewhat important	63 (11%)
	Not important	4 (1%)
Importance of fuel brand	Very important	329 (61%)
	Somewhat important	159 (30%)
	Not important	50 (9%)

[a] In 2019, gasoline consumption represented 63 percent and ethanol consumption represented 37 percent of the market (UNICA, 2020). Respondents using diesel were not allowed to continue the survey given the purpose of this study.
[b] Do you know what are biofuels? Yes/No.
[c] Respondents who expressed support for the government's promotion of biofuels were asked how they thought the government should motivate consumers to choose biofuels over traditional gasoline/diesel.
[d] Have you heard of the RenovaBio policy adopted by the Brazilian government to promote the use of biofuels in the country? Yes/No.

with respondents that were knowledgeable about biofuels than for those that did not know about biofuels. Similarly, respondents that reported to know about RenovaBio were significantly ($p > 0.10$) more likely to have a higher WTP for E2G than respondents that did not know about it.

From the variables associated with vehicle information and driving habits, owning a hybrid car had a statistically positive coefficient ($p >$

Table 3
Distribution of bid responses.

	2%	5%	8%	10%	20%	30%	40%	Total
E2G sold at a premium (bid2 > R$4.08)								
Yes	8	32	14	28	24	16	11	133
No	16	31	21	52	11	10	12	153
Total	24	63	35	80	35	26	23	286
E2G sold at a discount (bid2 < R$4.08)								
Yes	29	44	46	39	7	5	6	176
No	14	18	6	21	8	5	4	76
Total	43	62	52	60	15	10	10	252

Table 4
Response summary to Perceived Consumer Effectiveness (PCE) measure.

Perceived Consumer Effectiveness	Answer	*Scaled Score*[a]	N	%	*Item Corr.*[b]
PCE1 - It is worthless for the individual consumer to do anything about pollution.	Agree	1	123	23%	0.81
	Neutral	2	104	19%	
	Disagree	3	311	58%	
PCE2 - When I buy products, I try to consider how my use of them will affect the environment and other consumers.	Agree	3	384	71%	0.41
	Neutral	2	130	24%	
	Disagree	1	24	5%	
PCE3 - Since one person cannot have any effect upon pollution and natural resource problems, it doesn't make any difference what I do.	Agree	1	93	17%	0.78
	Neutral	2	88	17%	
	Disagree	3	357	66%	
PCE4 - Each consumer's behavior can have a positive effect on society	Agree	3	479	89%	0.43
	Neutral	2	50	9%	
	Disagree	1	9	2%	
	Mean of Total Scaled Scores	Standard Deviation		Cronbach Alpha[c]	
PCE score	10.38	1.67		0.50	

[a] Scaled scores were assigned values to reflect the positive and negative expression toward PCE. As such, PCE1 and PCE3 received a low scaled score for agreement with the negative statement and PCE2 and PCE4 received a high scaled score for agreement. The PCE score is the sum of the individual scaled scores to each of the items (PCE1.PCE4).
[b] Item correlation measures internal consistency of individual item responses to the sum of individuals' scaled responses. Item correlations greater than 0.30 warrant inclusion of an item in a total scale score (Spector, 1992).
[c] Cronbach alpha measures internal consistency as $\alpha = k/(k-1)^*(s_T^2 - \sum s_I^2)/s_T^2$, where k is the number of items in the scale, s_T^2 is the variance of the total scale scores, and s_I^2 is the variance of an individual item's scores. Higher internal consistency is evident with α closer to 1 (Spector, 1992). The greater the number of items in a construct the greater the chance for internal consistency.

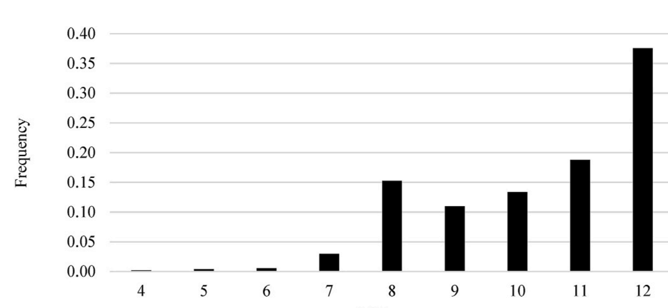

Fig. 2. Frequency of responses for Perceived Consumer Effectiveness.

Table 5
Summary description of explanatory variables used in the model.

Variable	Description
Information treatment	1 = Provision of information on E2G; 0 otherwise
Knowledge about biofuels	
Knowledge	1 = Knowledgeable about biofuels; 0 otherwise
RenovaBio	1 = Knowledgeable about RenovaBio; 0 otherwise
Hybrid	1 = Owns a hybrid vehicle; 0 otherwise
Fuel	1 = hydrous ethanol (E100) main fuel; 0 otherwise
Mileage	Reported mileage driven per week (continuous variable)
Income spent on fuel	1 = More than 10% of income spent on fuel; 0 otherwise
Socio-demographic	
High Income	1 = More than R$5000 per month; 0 otherwise
Middle Income	1 = Between R$2000-R$5000 per month; 0 otherwise
Low Income	1 = Less than R$2000 per month; 0 otherwise
Region NNE	1 = North and Northeast; 0 otherwise
Region CWSE	1 = Center West and Southeast; 0 otherwise
Region S	1 = South; 0 otherwise
Political affiliation	1 = Right-wing; 0 otherwise
Age	1 = Less than 40 years old; 0 otherwise
Education	1 = Bachelor's degree or above; 0 otherwise
Gender	1 = Female; 0 otherwise
Perceived Consumer Effectiveness	
PCE	Continuous variable ranging from 4 to 12

Table 6
Summary of coefficient estimates.

Variables	Coefficient	Standard error	z-value	P-value
Constant	5.094	0.378	13.460	0.000***
Information	0.114	0.092	1.240	0.215
Knowledge	0.252	0.118	2.130	0.034**
RenovaBio	0.181	0.104	1.740	0.082*
Hybrid	0.364	0.108	3.360	0.001***
Fuel	−0.197	0.113	−1.750	0.080*
Mileage	0.010	0.033	0.310	0.758
Income spent on fuel	−0.091	0.104	−0.880	0.379
Low income	−0.363	0.147	−2.470	0.013**
Middle income	−0.270	0.138	−1.960	0.050**
Region NNE	−0.038	0.156	−0.250	0.805
Region CWSE	−0.119	0.134	−0.890	0.374
Political affiliation	0.109	0.099	1.100	0.271
Age	0.139	0.106	1.320	0.188
Education	0.116	0.114	1.010	0.310
Gender	0.119	0.096	1.240	0.214
PCE	−0.084	0.030	−2.810	0.005***
Number of obs. = 538				
Log likelihood = -686.3				

*, **, *** indicate 10%, 5%, and 1% significance level, respectively.

0.01), while using mostly hydrous ethanol fuel had a statistically negative coefficient ($p > 0.05$). The negative coefficient for people using mostly hydrous ethanol fuel is puzzling. One possible explanation is that hydrous ethanol is perceived as a good substitute of E2G, that is, consumers already using an environmentally-friendly fuel such as hydrous ethanol are satisfied with their current environmentally-friendly choice and therefore are unwilling to modify their fuel choices.

From the demographic variables included in the model, only per capita income was statistically significant. Low and middle-income respondents were less willing ($p > 0.05$) to pay more for E2G than high-income respondents. Our results suggest that region, political affiliation, age, education, and gender do not have a statistically significant effect on respondents' WTP for E2G relative to conventional (E27) gasoline.

The negative PCE coefficient is puzzling and runs counter to our hypothesis that consumers with a high level of PCE would be willing to pay a higher premium than the average respondent. Thus, the Brazilian consumers' belief that their efforts can make a difference and contribute to solving environmental problems did not translate to a higher WTP for E2G. Inconsistencies between consumers' attitudes and their actual purchase behavior are found throughout the literature on sustainable consumption (Young et al., 2010; Terlau and Hirsch, 2015). As pointed out by Hanss and Doran (2020), "awareness of environmental issues and positive attitudes toward sustainable development often do not translate into consistent consumption behaviors" (p. 07–08). Issues with social desirability bias, understood as the tendency to underreport (overreport) socially undesirable (desirable) attitudes and behaviors, can also explain the counterintuitive relationship between PCE and WTP, in that respondents may have overstated their environmental attitudes but show less desirability to support those with their market decisions regarding E2G. Social desirability bias has been shown to have the potential to bias survey results and lead to erroneous research conclusions (Krumpal, 2013; Latkin et al., 2017).

Further reasons why attitudes in favor of sustainable development and consumption do not translate into consistent behaviors can be manifold. Consumers who are highly motivated to purchase environmentally and socially benign products may decide against or be kept from doing so due to situational constraints, including high price premiums, limited information provision (e.g., about the ecological footprint of product alternatives), or product availability (Terlau and Hirsch, 2015). Research in the domain of food consumption indicates that people are willing and even intend to buy environmentally and socially benign products, yet the market share of such products remain relatively low in many countries (Terlau and Hirsch, 2015).

4.3. Estimation of WTP

Using the results from the double-bounded dichotomous choice CV model and the descriptive statistics, we estimate the mean WTP following the Lopez-Feldman (2012) approach.[2]

$$WTP = \bar{z}_i' \beta \tag{3}$$

Confidence intervals around the estimated mean WTP are obtained using the delta method[3] (Greene, 2008). Mean WTP for the entire sample as well as selected subsamples are presented in Table 7. For the entire sample, the premium consumers were willing to pay for E2G relative to conventional E27 gasoline fell between 6.1 percent and 10.8 percent, with a mean value of 8.5 percent. Analyzing the WTP by subsamples, we estimated that respondents that received the information treatment were willing to pay a 9.8 percent premium, relative to a

Table 7
Estimates of WTP (in percentage premium from the reference price of gasoline)[a].

Sample	*Mean WTP*[b]	95% Confidence Interval	
Full Sample	8.5% ***	6.2%–10.8%	
Subsamples	Yes[b]	No[b]	*P-value*[c]
Information about E2G	9.8% ***	7.0% ***	0.215
Knowledgeable about biofuels	9.7% ***	3.5%	0.034 **
Knowledgeable about RenovaBio	11.5% ***	7.0% ***	0.082 *
Owns a hybrid vehicle	14.8% ***	5.9% ***	0.001 ***
Hydrous ethanol (E100) main fuel	4.8% **	9.6% ***	0.080 *
Middle income	4.6% **	11.2% ***	0.050 **
Low income	3.1%	11.9% ***	0.013 **
	PCE = 12	PCE = 8	
PCE score	5.2% ***	13.4% ***	0.005 ***

[a] The reference price for conventional gasoline (E27) is R$4.08/liter.
[b] *, **, *** indicate that the premium is different from zero at 10%, 5%, and 1% significance level, respectively.
[c] *, **, *** indicate that the difference in premium for each subsample is different from zero at 10%, 5%, and 1% significance level, respectively.

[2] This approach to the estimation of the WTP is similar to that proposed by Hanemann et al. (1991).
[3] Confidence intervals were estimated using the nlcom command in Stata®.

premium of 7.0 percent for those that did not receive the information treatment, but there was no statistically significant difference between both groups. Respondents knowledgeable about biofuels were willing to pay an average 9.7 percent premium relative to a 3.5 percent premium for those not knowledgeable, and the difference was statistically different ($p < 0.05$). The largest premium estimated for respondents was for those that own a hybrid vehicle (14.8 percent premium), and those that are knowledgeable about RenovaBio (11.5 percent premium). The WTP for E2G among low-income consumers was not statistically different from zero. Finally, respondents with PCE scores of 12 and 8 were willing to pay a 5.2-percent and 13.4-percent premium, respectively, and the difference was statistically different ($p < 0.01$).

4.4. Market implications of the estimated WTP

To understand what an 8.5 percent WTP premium for gasoline with E2G means in the context of the Brazilian biofuels market, we estimate the impact of alternative E2G blends in the E27 gasoline currently sold in the market. Under the assumption of competitive markets (market price equals marginal cost of production), and assuming marginal costs do not increase as the amount of blending increases, the price of E27 gasoline (P_{E27}) can be estimated using the price formula:

$$P_{E27} = [0.27 * (S_{E1G} * P_{E1G} + S_{E2G} * P_{E2G}) + 0.73 * P_{FF}] * (1 + tax) \tag{4}$$

Where P_{E1G}, P_{E2G}, and P_{FF} are the price of E1G, E2G, and fossil-fuel gasoline, respectively, S_{E1G} and S_{E2G} are the blend shares of E1G and E2G, respectively, and subject to ($S_{E1G} + S_{E2G} = 1$). Finally, *tax* is the sales tax on E27 gasoline.

We estimate a baseline scenario as follows. Jonker et al. (2015) estimated that the cost of E1G from sugarcane using basic technology (using conventional dehydration (azeotropic distillation) with low pressure steam cycle) in 2020 is 2010-US\$ 580/m^3, while the average cost for E2G from elephant grass and eucalyptus using basic technology (steam explosion pretreatment and enzymatic hydrolysis with bought enzymes for simultaneous saccharification and fermentation) in 2020 is 2010-US\$ 820/m^3. Deflating the value of the U.S. dollar by 19.2 percent from 2010 to 2020 (U.S. Department of Labor, 2020) and using the average exchange rate of R\$4.93/US\$ in the first six months of 2020 (Central Bank of Brazil, 2020), we estimate the cost of E1G and E2G in 2020 to be R\$ 3.41/liter and \$4.82/liter, respectively.

Given the 2020 market price of E27 (R\$ 4.08/liter) and E1G (R\$ 3.41/liter), the average sales tax on E27 gasoline of 45 percent (Petrobras, 2020), and the fact that essentially all ethanol currently used in E27 is E1G ($S_{E1G} = 1$), using equation (4) we estimate the price of fossil-fuel gasoline used in E27 gasoline to be R\$ 2.59/liter in 2020.

Using the E27 price formula (4) and the 2020 price of E27, E1G, E2G, and fossil-fuel gasoline, we estimate that a 1-percent increase in the blend of E2G will increase the price of E27 gasoline by 0.135 percent (Fig. 3). Hence, according to the baseline scenario, a price premium of 8.5 percent could support an E27 gasoline made up of 62.5 percent E2G without the need of government price support/subsidies.

We assessed the robustness of the market implications of the estimated WTP premium for gasoline with E2G under two future alternative ethanol technology scenarios. Scenario 1 assumes that the cost of producing E1G from sugarcane and E2G from elephant grass and eucalyptus using the basic technology in 2030 decreases to US\$ 525/m^3 and US\$ 740/m^3 as projected by Jonker et al. (2015). Scenario 2 assumes that the production of E1G is optimized through the use of molecular sieves and high-pressure boilers, while the production of E2G is optimized through the use of liquid hot water pretreatment, followed by enzymatic hydrolysis (with on-reactor enzyme production) and fermentation using consolidated bioprocessing. These assumptions yield a production cost of US\$ 475/m^3 and US\$ 450/m^3 for E1G and E2G in 2030, respectively (Jonker et al., 2015). For both scenarios, the price of fossil-fuel gasoline in 2030 was estimated using the 2020 price of R\$ 2.59/liter, and the change in the price of motor gasoline from 2020 to 2030 (24%) projected by the U.S. Energy Information Administration (2021).

Fig. 4 below shows that in scenario 1, a price premium of 8.5 percent could support an E27 gasoline made up of 81.9 percent E2G without the need of government price support/subsidies. The increase in the E2G blend that the price premium estimated in this study could sustain results from the fact that the cost of production of E1G and E2G decrease from 2020 to 2030 (by 9.5% and 9.8%, respectively), while the price of fossil-fuel gasoline increases by 24%, which makes E2G blending relatively less expensive.

The results from scenario 2 suggest that the production of E2G using the optimized technology will actually lead to a decrease in the price of E27 because the cost of production (and by the assumption of competitive markets, the market price) of E2G will decrease by 45.1% from the baseline, making E2G cheaper than E1G (whose price decreases by 18.1%) and fossil-fuel gasoline. In other words, if the assumptions for scenario 2 materialize, then using all E2G in the blending formula will be the best alternative both economically (because it leads to lower gasoline prices) and environmentally.

5. Conclusions and policy implications

This study assessed Brazilian consumers' WTP for E2G using a survey of 538 respondents that drive gasoline cars. Two main limitations of the study that should be considered revolve around the quality of the sample, and the economic assumptions followed to assess the market implications of our findings. As with any survey, the quality of the sample determines the external validity of the results. Due to the lack of data on the socioeconomic conditions of the population of interest, that is, Brazilian adults that drive gasoline cars, the only comparable population

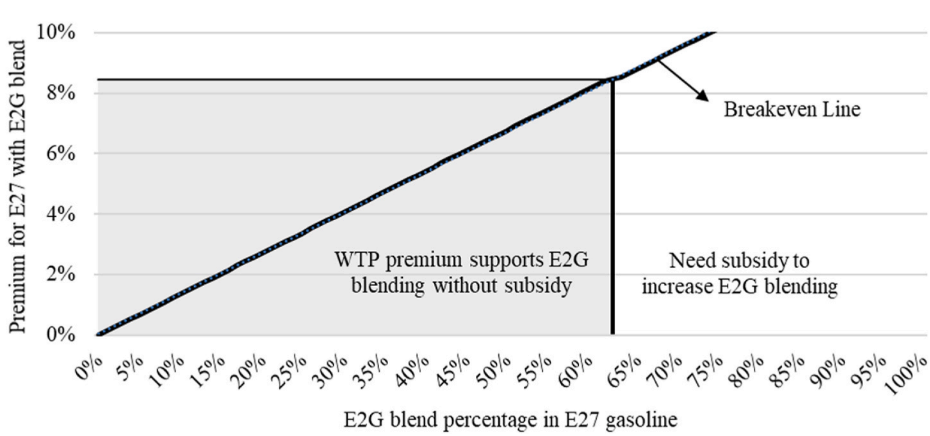

Fig. 3. Price premium for E27 gasoline with E2G blend as a function of the E2G blending percentage.

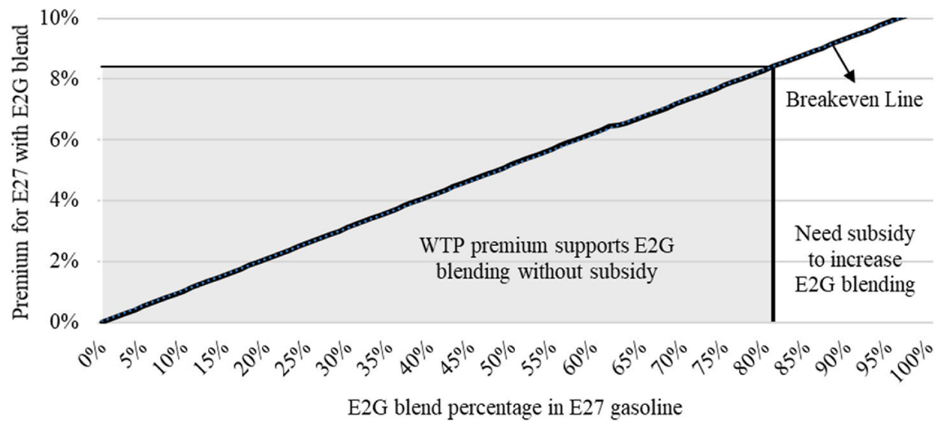

Fig. 4. Price premium for E27 gasoline with E2G blend as a function of the E2G blending percentage in 2030 using the basic E1G and E2G technology.

data is that of the entire Brazilian population, relative to which, our sample has a higher level of education and income. This may reflect potential biases, and should serve as a warning to use these results with caution. Moreover, the analysis of the market implications of the WTP for E2G is based on commonly used economic assumptions that could deviate from the actual behavior of the market. Although the scenario analysis addresses the impact of changes in production costs and prices, further information on market competition and E2G cost of production can be used to refine the analysis.

E2G has the potential to play a significant role in meeting environmental targets established by Brazil at the 2015 UNFCCC. Despite the advantages of E2G, most production of ethanol in Brazil is limited to E1G produced from sugarcane and the country has not created policy or market mechanisms to increase the production of E2G. In this context, the extent to which a market for cellulosic ethanol emerges in Brazil will depend in part on the extent to which consumers in Brazil demonstrate a preference for a cellulosic ethanol blend.

The results suggested that, on average, Brazilian consumers are willing to purchase E2G at an 8.5 percent premium price compared to conventional E27 fuel. This result is consistent with previous studies that estimated the mean WTP for the same product. For instance, Li and McCluskey (2017) found that the average consumer in three cities in the U.S. was willing to pay an 11 percent premium for E2G, and Mamadzhanov et al. (2019) found that South Korean consumers are willing to pay an average of 4.3 percent more for E2G relative to conventional fuel. Unlike the findings by Mamadzhanov et al. (2019) in South Korea, our findings suggest that the information treatment does not significantly affect consumers' WTP for E2G. However, previous knowledge about biofuels did have a significant impact, which implies that further educating consumers about biofuels might be a suitable way to improve the viability of creating a consumer-driven market for E2G. In addition, consumers who use mostly E27 gasoline, and those living in high-income households, were more likely to be willing to purchase E2G with a premium, which suggests that targeting marketing activities to those segments may be the most efficient way to promote a market for E2G in Brazil.

Interestingly, the results of this study suggest that the higher the level of PCE, the lower the premium consumers are willing to pay for E2G. In addition to social desirability bias, there are various factors that could impact the behavior consistency of consumers who have attitudes in favor of sustainable products. Consumers who are motivated to purchase environmentally friendly products may not do so due to high price premiums or limited information (Hanss and Doran, 2020). Thus, it could be that respondents with a high level of PCE did not translate E2G as a more sustainable consumption alternative and perhaps so because of insufficient knowledge. Another possible explanation could be that respondents with a high level of PCE had less income. Although the correlation between PCE and knowledge (−0.084), and between PCE and low income (0.056) do not provide support for these two explanations. More research is needed to elicit the behavior of Brazilian consumers with high levels of PCE.

We estimate that an 8.5 percent premium for E27 gasoline with E2G in the blend is large enough to currently support a 62.5 percent E2G blend. Higher blending requirements will require public polices (e.g., price subsidies or tax breaks) to keep the value of gasoline consistent with what consumers are willing to pay. Higher market prices will likely result in lower gasoline demand and ultimately reduce the market for E2G. Moreover, Jonker et al. (2015) estimate that the production cost of E2G has the potential to decrease to levels similar to E1G by 2030. The results from two future 2030 scenarios assuming no technology changes but reduced production costs (scenario 1), and the adoption of optimized technologies (scenario 2) suggest an even higher feasibility for a E2G market based solely on its competitiveness vis-à-vis E1G and fossil-fuel gasoline. Such a gain in the efficiency and competitiveness of E2G in the coming decade means that the 8.5 percent premium estimated in this study will be able to support a larger share of E2G blending without policy intervention.

In conclusion, results suggested that Brazilian consumers who are generally more knowledgeable about biofuels are more likely to pay a premium for gasoline blended with E2G. Results also indicated a potential market for E2G among Brazilian consumers who purchase mostly gasoline fuel. Moreover, income may also influence consumers' WTP for E2G. This assessment of consumers' WTP for E2G in Brazil enables policymakers to make better informed decisions about biofuels in the country. In this context, the finding that consumers are willing to purchase E2G at an 8.5 percent premium price compared to the current E27 fuel is particularly relevant considering that the more willing consumers are to pay a premium for E2G, the less the need for government intervention.

In the broader context, understanding the dynamics underlying consumers' support for E2G in Brazil is critically important for the country to achieve the goals set internally by Renovabio, as well as internationally by Brazil's NDC towards achieving the objective of the United Nations convention on climate change. It is also a key issue in the larger national debate in Brazil over the regulation of environmental and energy issues. With the inauguration of President Bolsonaro in 2019, a turn in policy direction questioning the impact of climate change is a potential threat to the biofuel industry. Finally, consumer acceptance of E2G in Brazil could result in lower emissions of GHG, and thus help address some of the social issues associated air pollution in Brazil.

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CRediT authorship contribution statement

Teresa Cristina Garcia: Conceptualization, Methodology, Software, Formal analysis, Writing – original draft, Writing – review & editing. **Alvaro Durand-Morat:** Conceptualization, Methodology, Software, Formal analysis, Writing – original draft, Writing – review & editing, Visualization, Supervision, Project administration, Funding acquisition. **Wei Yang:** Methodology, Software, Formal analysis. **Michael Popp:** Conceptualization, Methodology, Writing – review & editing. **William Schreckhise:** Conceptualization, Writing – review & editing.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.enpol.2021.112729.

Appendix A. Example of the Contingent Valuation Question used in the Survey

(1) Suppose the price of gasoline C (E27 with first-generation ethanol) is R$4.08/liter. If the price of gasoline with a second-generation ethanol blend is R$3.26/liter, would you be willing to purchase it?
- Yes (apply (2a) below)
- No (apply (2b) below)

2a) Now, if the price of gasoline with a second-generation ethanol blend is R$3.67/liter, would you be willing to purchase it?
- Yes
- No

2b) Now, if the price of gasoline with a second-generation ethanol blend is R$2.45/liter, would you be willing to purchase it?
- Yes
- No

Appendix B. English Translation of Information Statement

In recent studies, scientists have shown that second-generation ethanol (produced from sugarcane bagasse, straw, and tips) produces considerably lower environmental impact and greenhouse gas emissions compared to the first-generation ethanol (produced from sugarcane). Second-generation ethanol can be produced either from waste products or from feedstocks that can be grown on marginal lands not normally used for food production. In addition, second-generation ethanol can have higher yields per hectare, which can make it less of a competitor for food production. However, the disadvantage of second-generation ethanol is that it is currently more expensive than first-generation ethanol.

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