The Demand for Voluntary Carbon Dioxide Removal: Experimental Evidence from an Afforestation Project in Germany

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ABSTRACT *This study explores individual willingness to pay (WTP) for carbon removal through afforestation as a complementary climate change mitigation strategy. Using a framed-field experiment, we assess the impact of local co-benefits and geographic location on WTP. We find that participants strongly favor voluntary climate change mitigation through forestry-based emission removal. Emphasizing co-benefits does not significantly alter WTP in our municipal tree-planting project. A follow-up survey indicates a high awareness of co-benefits, suggesting that unobserved priors may influence WTP results. Trust levels are higher for forestry-based removal than for established market-based carbon avoidance, suggesting preferences for understandable mitigation measures with tangible co-benefits.* (JEL Q23, Q51)

1. Introduction

Although emission avoidance strategies, such as the development of low-carbon technologies, the rapid expansion of renewable energy sources, and improvements in energy efficiency and storage, will be essential to substantially cut back future emissions around the world, there is growing consensus that avoidance alone will not be enough to reach net zero greenhouse gas (GHG) emission targets (Lawrence et al. 2018; Nieto, Carpintero, and Miguel 2018; Fekete et al. 2021). Attention is therefore increasingly being paid to climate change mitigation via carbon dioxide removal (CDR) as an important supplementary tool to counterbalance hard-to-abate residual emissions.

By now, CDR is an element of all the scenarios by the Intergovernmental Panel on Climate Change that limit global warming to 2°C (Shukla et al. 2022; Smith et al. 2023). Among available CDR methods, establishing forest carbon sinks is one of the few measures for which large-scale CDR may be possible (Shukla et al. 2022).[1] Forest carbon sinks have a potential to support climate stabilization (Lewis et al. 2019; Austin et al. 2020; Cook-Patton et al. 2020; Forster et al. 2021) and decrease peak warming over the short- to midterm (Matthews et al. 2022). They are acknowledged for their cost-effectiveness, with lower marginal cost compared with emissions avoidance measures (Richards and Stokes 2004; van Kooten et al. 2004; Gren and Aklilu 2016; van Kooten 2017).[2] In addition,

[1] For a comprehensive overview of CDR literature and the potentials, costs, and implications of deployment, see Fuss et al. (2018) and Shukla et al. (2022).

[2] Cost calculations vary considerably, however. According to a metaregression analysis by van Kooten et al. (2004), the costs of forest carbon sequestration vary between US\$12.7 and US\$70.9/tCO_2. This is explained by varying model assumptions on, for example, the rate of carbon uptake, previous land usage, the risks of natural disturbances, and the considered time span (Bateman and Lovett 2000; Núñez, Nahuelhual, and Oyarzún 2006; van der Horst 2006; Canadell and Raupach 2008; Ninan and Inoue 2013). Carbon uptake crucially depends on various factors, including the tree species in question (e.g., indigenous vs.

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they provide valuable co-benefits, including recreation, timber, biodiversity, improved air quality, natural regulation of atmospheric temperature, soil protection, and hydrologic functions.[3]

Establishing forest carbon sinks (e.g., through afforestation or reforestation)[4] has garnered increasing political and public attention and accounts for about 99% of currently deployed CDR land measures (Smith et al. 2023).[5] Forest carbon sinks were discussed at the 27th annual UN Climate Change Conference of the Parties in 2022 and in the EU Forest Strategy for 2030, which commits EU member states to reverse forest loss and pledge to increase forest coverage. However, increasing the tree coverage of land is complex. On the one hand, land use conflicts may arise because the land for planting trees can serve multiple purposes, and creating new spaces for forest carbon sinks may encounter public resistance (Holl and Brancalion 2020). On the other hand, the valuation for forest carbon sinks, as a mitigation measure, might depend on, and be positively influenced by, the potential co-benefits of such carbon sinks. This is particularly true for the highly palpable forest co-benefits. With the shift toward actively integrating forest carbon sinks into climate policies, there is a need to develop a comprehensive understanding of public preferences in this regard and how markets and individuals value carbon sinks (Holl and Brancalion 2020; Shrestha et al. 2022).

The primary objective of this article is to assess the public's willingness to voluntarily contribute to climate change mitigation through forestry-based carbon removal. Embedded in this overarching question, we aim to gain a deeper understanding of how local co-benefits influence willingness to pay (WTP) for carbon removal in a local municipal tree-planting project. This is inspired by the notion that actively communicating co-benefits can encourage additional mitigation activities (MacKerron et al. 2009; Longo, Hoyos, and Markandya 2012; Torres et al. 2015; Bain et al. 2016; Baranzini et al. 2018). Recognizing that individuals in proximity are more likely to directly benefit from local co-benefits and therefore may place a comparatively higher valuation on these benefits (Brouwer, Martin-Ortega, and Berbel 2010; Abildtrup et al. 2013; Schaafsma et al. 2013; Torres et al. 2015), we seek to better understand how much the perceived value of these local co-benefits depends on how close participants are to the afforestation project.

To this purpose, we conducted a first incentivized, framed-field experiment to elicit the revealed WTP for forestry-based carbon removal in a broad German population sample. In our experiment, study participants were randomly divided into two groups and asked to give real money to support a local afforestation project and thus to remove CO_2. For the control group, the contribution decision was neutrally framed and described the need for carbon removal as a climate mitigation activity, the carbon sequestration potential of trees, and the afforestation project. In the treatment group, we provided the same information as in the control group but highlighted

nonindigenous, diversity), tree growth and carbon sequestration rates, the climate zone, land suitability, harvest times, and management (Newell and Stavins 2000; Neumann et al. 2016; Obersteiner et al. 2018; Bastin et al. 2019; Pires 2019; Matthews et al. 2022). In addition, most studies fail to adequately take consider the ongoing costs of maintenance to ensure that the expected carbon sequestration is realized. When the opportunity costs of land use are taken into account, the average costs rise significantly (van Kooten et al. 2004). For example, forests provide ecosystem services that are categorized in terms of use and nonuse values (Bateman and Lovett 2000; Núñez, Nahuelhual, and Oyarzún 2006; van der Horst 2006; Canadell and Raupach 2008; Ninan and Inoue 2013). Local co-benefits accrue especially in term of use values such as recreation, education, tourism, timber, biodiversity, carbon storage, improved air quality, soil protection, and hydrologic functions. Nonuse values include the bequest value, altruistic value, and existence value.

[3] Co-benefits describe the positive side effects mitigation actions have on other dimensions beyond climate change (Shukla et al. 2022). While the primary public good component (i.e., the benefits of removed GHG emissions) is global in scale, most co-benefits accrue in a predominantly local context.

[4] Climate change mitigation scenarios typically make no differentiation between reforestation and afforestation despite the measures' different overall environmental impacts (Shukla et al. 2022). We focus on afforestation, which converts nonforest land (e.g., agricultural land or brownfields) to forest land. Reforestation describes the replanting of trees in existing forests that are depleted or destroyed.

[5] Other CDR measures such as bioenergy with carbon capture and storage, direct air carbon capture and storage, biochar, and enhanced rock weathering are expected to be implemented on a large scale over the next century (Smith et al. 2023).

the local co-benefits of the project. To understand whether participants show different valuations for forest carbon sinks and their co-benefits based on spatial variations, we used a German population sample and leveraged the availability of the geographical position of each subject. This allowed us to construct a distance measure, which we could use to investigate the distance-decay effect on our revealed WTP. Furthermore, we used the geographical dispersion of participants to add and control for heterogeneous geodata (e.g., forest coverage, urbanization level) to assess whether WTP is influenced by factors such as varying densities of existing forest coverage. To augment our framed-field experiment, we conducted a survey among 567 students to shed more light on general attitudes toward, and knowledge about, carbon removal and avoidance.

We find that participants exhibit a high WTP for voluntary climate change mitigation implemented via forestry-based CDR measures. We conjecture that these results may stem from a preference for simple climate mitigation measures with tangible co-benefits as well as (nonobserved) beliefs and priors of the subjects. However, we do not find that emphasizing co-benefits further increases WTP for carbon removal. When subjects are already aware of the co-benefits, stressing them may not have an additional effect. The survey conducted among a student sample that had not participated in the experiment supports this conjecture, revealing knowledge about forest co-benefits. In addition, subjects feel better informed about, and have greater trust in, forest measures compared with alternative GHG mitigation polices, such as the EU Emission Trading Scheme (ETS).

Our findings contribute to the growing literature about the public's perception and acceptability of natural CDR methods in general (Wolske et al. 2019; Cox, Spence, and Pidgeon 2020; Bellamy 2022; Merk et al. 2023) and particularly to questions involving the feasibility of (large-scale) carbon removal, associated socioecological contexts, and potential trade-offs (Buck 2016; Wenger, Stauffacher, and Dallo 2021). Shedding light on this issue can help policy makers "design financial incentives . . . that target the conservation of forests to preserve the otherwise nonmarketed ecosystem services that they provide" (Taye et al. 2021, 2). Previous studies typically evaluate people's WTP to mitigate climate change in the context of carbon avoidance. Study participants were asked to personally contribute to mitigation by purchasing and withdrawing emissions allowances from existing ETSs. Revealed-preference studies with incentive compatible settings find a low but positive willingness to voluntarily pay for emission avoidance (Löschel, Sturm, and Vogt 2013; Diederich and Goeschl 2014; Löschel et al. 2021). These studies also report a higher willingness to support domestic avoidance options (Anderson and Bernauer 2016; Buntaine and Prather 2018; Diederich and Goeschl 2018), which is predominantly driven by preferences for local co-benefits (Löschel et al. 2021).

However, so far, it has remained unclear to what extent insights from experimental studies on emission avoidance can be carried over to forestry-based emission removal scenarios, given the different characteristics of public goods. This study contributes to closing this gap. Compared with climate contributions made through the ETS, forest carbon sinks are an easily understandable and tangible climate measure for individuals. Moreover, they yield a broad range of local co-benefits. From stated-preference methods, we know these co-benefits are positively valued (Rodríguez-Entrena, Espinosa-Goded, and Barreiro-Hurlé 2014; Torres et al. 2015).[6] Evidence based on revealed-preference methods, is however, scarce. To the best of our knowledge, Baranzini, Borzykowksi, and Carattini (2018) is the only revealed-preference study that investigates voluntary contributions to a reforestation project to offset carbon emissions (through supporting national and international forest projects) in a lab setting with a student sample and also investigates the impact of co-benefits at the intensive margin. The authors of that study investigate how the co-benefits information influences how participants split an already determined amount between a national

[6] These findings contrast with evidence from stated-preference approaches, which usually show a positive WTP for climate protection (MacKerron et al. 2009; Achtnicht 2012; Uehleke and Sturm 2017).

and an international project. Our study, in contrast, uses a field experimental approach to reveal WTP for national forestry-based carbon removal in a broader population sample and evaluates the impact of co-benefits on the willingness to contribute to the public good at the extensive and intensive margins.

2. Methods

Framed-Field Experiment

Our framed-field experiment was conducted on March 16–25, 2020. It was attached to an online survey that was conducted jointly with the University of Münster and a German online price comparison website that allows customers to compare electricity service plans offered by different providers.[7] Personalized survey invitations were sent via email to the platform's registered users, who come from the general population. The invitation included information on the purpose of the survey and the time required to complete it. It also explained that participants would receive a fixed payment of €20 for completing it and an additional variable payment of between €6 and €40, depending on their answers. The final payment was made through a voucher redeemable at over 500 stores. The survey was thematically unrelated to our experiment and investigated consumer behavior in the retail electricity market. Our experiment was placed at the end of this survey. Participants were not aware of the actual experiment in which we scrutinized their propensity to contribute to environmental protection under two different treatments.

In our survey design, we introduced a donation option as an experimental variation on the conventional financial reward for participating. Because of our design, we were unable to collect postexperiment data on, for example, individual beliefs and motivations. Instead, we were only able to collect standard economic preferences, in addition to the age, gender, and geographical location of each participant.[8] We acknowledge that a subject's location during survey participation was not necessarily the same as their place of residence. However, the survey took place at the beginning of the German COVID-19 lockdown. Childcare facilities and schools were closed, remote work was encouraged, and public life was reduced. These factors increased the chance that participants were at home.

After the subjects completed the survey, we informed them that they could support an afforestation project by making a donation from the fixed share of their payment for participating.[9] To implement a real donation, we collaborated with the city of Mannheim, which was going to be hosting the National Garden Show in 2023.[10] For the event, a disused military base had been transformed into green areas, and approximately 1,000 trees were planted, creating a local carbon sink. Subjects were asked how much they would be willing to donate to the afforestation project, given 100 kg of CO_2 removal from the atmosphere.[11]

We also introduced a treatment that addressed co-benefits. The survey program randomly divided subjects into two groups: the sink (S) and the co-benefit (CBS) treatments. In both treatments, the subjects received relevant information on the need for global climate protection. This ensured that each participant had the same basic knowledge regarding climate change and the role played by trees in climate change mitigation efforts. We explained the role of forest carbon sinks

[7] See Appendix A1 for a detailed description of the sampling procedure and information on the electricity platform.

[8] The questions relate to the Global Preference Survey (Falk et al. 2016, 2018) and the Need for Cognition Scale (NFC-K) (Beißert et al. 2014).

[9] At this stage of the survey, participants did not know how much of the additional payment they would receive. Consequently, we only gave them the opportunity to donate their fixed reimbursement, which was the same for all participants.

[10] The German National Garden Show is a horticultural exhibition that enjoys great popularity. The last show attracted 1.5 million visitors. It takes place every two years in a different city and lasts for six months.

[11] The selected volume of CO_2 is identical to the amount offered to participants in related studies (e.g., Löschel, Sturm, and Uehleke 2017). The maximum WTP in our settings was equal to the individual's fixed remuneration. The maximum amount was rarely donated by participants, perhaps because it would have resulted in a very high WTP of €2,000/tCO_2.

in climate protection and gave subjects information on the average CO_2 absorption capacities of trees using the example of a beech tree, which, on average, absorbs 100 kg of CO_2 over eight years (Klein 2009). To make this information more relatable, we explained that 100 kg of CO_2 is approximately equal to the emissions caused by a 550 km car trip. Finally, we gave subjects information on the local afforestation project and explained that their donation would be used to plant additional trees. In the CBS treatment, by contrast, we also included information on local co-benefits. Specifically, we highlighted the project's advantages in terms of recreational opportunities, improved local air quality, regulation of local atmospheric temperature, and greater biodiversity (see Appendix A for an overview and detailed information). Only after receiving this information were subjects asked to indicate their WTP. The likelihood of donating (extensive margin effect) and the amount donated (intensive margin effect) were the main outcome variables for our analysis.

Observational Data on Location

The attitude shown by participants toward the afforestation project may be affected by the distance-decay effect and the subjects' geographic locations. Previous research has shown that WTP is affected by the accessibility of substitutes (e.g., other forested areas). Czajkowski et al. (2017), for example, find that WTP is higher when surrounding forests are scarce. To control for this, we matched our experimental data with geodata from the INKAR database (BBSR 2020) maintained by the German Federal Office for Building and Regional Planning. Most indicators have been collected on a continuous basis since 1995 and are granular to the district level. We drew on indicators of forest coverage, installed wind energy capacity, volume of recreational and agricultural space, urbanization level, and habitat density.

3. Literature and Hypotheses

Individual costs that accrue from conservation efforts typically outweigh individual benefits from increased environmental quality, so strong free-riding incentives are expected to prevent contributions to global public goods, such as GHG mitigation. However, vast experimental evidence demonstrates that individuals do contribute privately to public goods (for comprehensive literature reviews, see Ledyard 1995; Chaudhuri 2011). This finding has been confirmed in studies estimating WTP for emission avoidance. In such studies, subjects are asked whether and how much they would pay to prevent emissions based on the purchase and withdrawal of emission allowances from an ETS, either using stated-preference or revealed-preference methods (MacKerron et al. 2009; Achtnicht 2012; Löschel, Sturm, and Vogt 2013; Diederich and Goeschl 2014; Uehleke and Sturm 2017; Löschel et al. 2021).

Establishing forest carbon sinks is increasingly being recognized as a promising supplementary path in climate change mitigation efforts, so it is important to understand how market participants value carbon sinks as a climate action measure, particularly in light of the unique characteristics of public goods. Thus far, the question remains as to whether the empirical insights regarding individual emission avoidance that have been developed can be carried over to situations in which subjects can use real money to contribute to CO_2 removal. Insights from stated-preference studies show that individuals do inhibit a positive WTP for carbon removal via forests.

Brey, Riera, and Mogas (2007) use a choice experiment to elicit a valuation for an afforestation program in Catalonia, Spain. In terms of carbon sequestered, they find a WTP of €1.74×10^{-4}/tCO_2 per year. Rodríguez-Entrena et al. (2012) and Rodríguez-Entrena, Espinosa-Goded, and Barreiro-Hurlé (2014) use data from the same experiment and report a weighted individual WTP of €4.28×10^{-6}/tCO_2 per year for carbon sequestration through olive groves in Andalusia, Spain. Torres et al. (2015) use a choice experiment to estimate WTP for carbon sequestration through an afforestation project in Mexico. They report mean WTPs for four cities ranging between €5.57 and €11.39/tCO_2. Tolunay and Başsüllü (2015) use the contingent valuation method to measure WTP for the carbon sequestration service of forests in Turkey. They find a WTP of €0.07/tCO_2. Baranzini, Borzykowski, and Carattini (2018) investigate voluntary contributions to a reforestation project to offset carbon emissions in a lab setting based on a student sample. They report that, on average, participants contributed about 80% (6 CHF; approximately €6) of their average endowment (7 CHF; approximately €7).

Considering the lack of revealed-preferences studies on WTP for carbon removal and the well-reported difference between stated and revealed WTP estimates for emission avoidance, we base our first hypothesis on standard assumptions regarding the voluntary provision of public goods. Our first statistical hypothesis (H_1) on WTP to contribute to carbon removal in the S treatment (WTP_S) thus reads as follows: H_0: $WTP_S = 0$; H_A: $WTP_S > 0$.

Recent research suggests that co-benefits can play an important role in voluntary emission avoidance. Communicating these benefits can encourage mitigation activities (Bain et al. 2016). Previous studies have generally focused on emission avoidance through allowance retirements, eliciting either stated or revealed preferences. Using a revealed-preference approach, Löschel et al. (2021) and Feldhaus et al. (2022) find that co-benefits have a positive and significant effect on individual contributions to climate change mitigation. Diederich and Goeschl (2018) find that highlighting co-benefits has no effect. However, it must be noted that in their setting, the co-benefits arise in connection with an emission avoidance project in a developing country. In this way, the co-benefits do not accrue directly to the experimental subjects but to a distant population. Similarly, MacKerron et al. (2009) find a substantially higher (albeit hypothetical) WTP for carbon-offsetting projects that include co-benefits. Longo, Hoyos, and Markandya (2012) find that stated WTP estimates to support climate change mitigation policies are higher when co-benefits are considered. This preference for co-benefits is also reflected in the voluntary carbon market. The Forest Trends' Ecosystem Marketplace (2022) report finds that carbon credits offered within projects that provide additional co-benefits enjoy a price premium.

While research on the economic valuation of the additional goods and services provided by forest ecosystems has grown exponentially, studies estimating the impact of co-benefits on WTP for carbon removal are rare.[12] A stated-preference study by Tolunay and Başsüllü (2015) finds that respondents who attach importance to the co-benefits of forest ecosystems are willing to pay more for the forest. Torres et al. (2015) find that their participants are willing to pay higher carbon prices for carbon sequestration in nearby forests, thus reflecting the valuation of local co-benefits. Rodríguez-Entrena, Espinosa-Goded, and Barreiro-Hurlé (2014) find that WTP is higher in areas and for individuals who would directly benefit from a soil management program. However, the extent to which emphasizing the co-benefits of afforestation in a municipality project affect revealed WTP remains an open question.

To the best of our knowledge, Baranzini, Borzykowski, and Carattini (2018) is the only other study that investigates revealed WTP estimates for mitigation through removal. They find that highlighting local co-benefits does not increase support for a domestic (Switzerland) reforestation program compared with an international (Nicaragua) program. In contrast to our setting, they use a lab experiment with a student sample, while we use a general population sample. In addition, they introduce co-benefits information only in a second step. First, participants receive information solely on the possibility of offsetting their carbon emissions through a reforestation program. During this initial stage, participants decide whether and how much money they want to allocate to the purchase of carbon offsets. Only then are treatments (i.e., information on the co-benefits of the domestic program) given, followed by allowing participants to decide how to allocate the amount specified in stage one between the domestic and the international reforestation project). Consequently, Baranzini, Borzykowski, and Carattini (2018) only measure the extent to which co-benefits

[12] This research applies different valuation techniques (for an overview of methods, see Freeman 2003) across various categories (conservation type, forest type, type of ecosystem). Metastudies (Barrio and Loureiro 2010; Mengist and Soromessa 2019; Taye et al. 2021) provide a comprehensive picture of how forest services are valued.

information influences the allocation decision between the two options. In contrast, we can investigate in our setting whether co-benefits information has an effect on the propensity to give and the amount given.

We expect contributions to be higher when the local benefits of afforestation are stressed compared with a setting in which they are not stressed ($WTP_{CBS} > WTP_S$). However, the provision of these local public goods (e.g., improved local air quality, higher biodiversity) may trigger additional free-riding behavior. If and how subjects react to information stressing local co-benefits remains an open question. Accordingly, we formulate our second hypothesis (H_2) as follows: H_0: $WTP_{CBS} = WTP_S$; H_A: $WTP_{CBS} > WTP_S$.

Although the primary public good component (i.e., the benefits of reduced GHG emissions) is global in scale, most of the co-benefits accrue in a local context, thus highlighting the importance of geographical distance from a project site. From ecosystem services studies, we know that the (stated) valuation of goods and services is subject to a distance-decay function (Bateman et al. 2006; Del Saz Salazar and García Menéndez 2007; Schaafsma et al. 2013; Bakhtiari et al. 2018). This has also been reported for forest ecosystems (Brouwer, Martin-Ortega, and Berbel 2010; Abildtrup et al. 2013; Schaafsma et al. 2013; Torres et al. 2015). Specifically, subjects living close to a forest project are more likely to benefit from the local co-benefits that stem from the use values of a forest ecosystem. As distance increases, the probability of an individual benefiting from co-benefits decreases, potentially influencing WTP. The literature also reports a negative relationship between nonuse values and distance, which is predominantly driven by a social-distance mechanism. People have a higher WTP when they can personally identify with, or feel connected to, a given project or program (Jones and Rachlin 2006; Strombach et al. 2014). A similar relationship is found for WTP for emission avoidance: domestic offsetting options are often preferred over international ones (Anderson and Bernauer 2016; Buntaine and Prather 2018; Diederich and Goeschl 2018), a tendency that is mostly driven by preferences for local co-benefits (Löschel et al. 2021).

By emphasizing local co-benefits, the advantageous but locally bounded components of a project become more apparent to subjects. In this way, we expect an interaction between distance and our CBS treatment. If local favoritism holds in our setting, given the geographical dispersion of subjects, we can expect a difference between those who are located close to the afforestation project and those who are located farther away. If this holds true, we can reject the null hypothesis (H_0: $\rho(WTP,c) = 0$) in our third hypothesis (H_3), which captures the correlation ρ between the spatial proximity c to the afforestation project and WTP as follows: H_0: $\rho(WTP,c) = 0$; H_A: $\rho(WTP,c) > 0$.

4. Results

We sent 3,303 invitation emails for our survey on consumer behavior in the retail electricity market. As noted, this survey included our WTP question at the end. A total of 359 subjects started the survey, and 160 completed it.[13] The median time participants spent answering the questions was 10.99 minutes (p10 = 4.5 mins, p90 = 40 mins).[14] We thus had a response rate of 5%, which is a typical rate for online experiments with real people who are not members of an experimental pool. The mean participant age was 44, and 30% were female. In 2020, the average age of the German population was 44.6 years, and the proportion of women was 50.7%. The S treatment has 73 observations, and the CBS treatment has 87. Balance tests on age and gender found a balanced sample. Appendix B provides a description of the experimental and geographical variables (Appendix Tables B1–B5 and B6–B8, respectively). In total, the subjects donated €1,797, which was used to plant 2.5 Caucasian wingnut trees of 5–6 m in height in May 2021.[15]

[13] For the optimal sample size calculation, we ran a statistical power analysis. With our treatments sample size, we are able to detect a statistical power of more than 0.7. See Appendix A3 for a detailed description of the power analysis.

[14] Due to the fixed (€20) and variable (€6–€40) payment, the compensation-effort ratio varies between subjects. On average, participants received €27.67.

[15] The donations from this experiment were complemented with donations from another experimental study on

Table 1
Extensive and Intensive Margin Effects by Treatments

	Hurdle (1)		Hurdle (2)	
	First Stage	Second Stage	First Stage	Second Stage
Co-benefits	−0.24	−2.14	−0.23	−1.14
	(0.21)	(264)	(0.21)	(2.36)
Age			0.00	0.17*
			(0.01)	(0.07)
Female			−0.19	−2.60
			(0.22)	(2.96)
Constant	0.52***	6.24*	0.63+	−0.31
	(0.15)	(2.67)	(0.33)	(4.73)
Constant	2.24***		2.17***	
	(0.15)		(0.14)	
Observations	160		160	

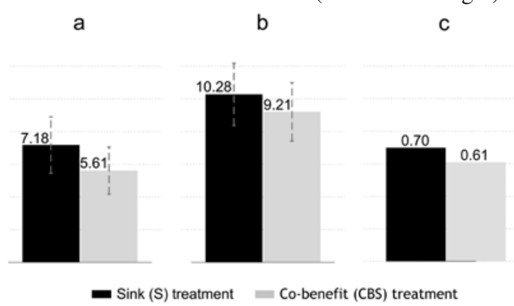
Note: The table shows the corresponding regression analysis based on two (with and without further control variables) two-stage hurdle models. The first stage consists of probit regression models (where the dependent variable is equal to one for positive donations). The second stage consists of truncated linear regression models (where the continuous dependent variable is the donation amount, assuming donation is made). Robust standard errors are in parentheses.
* $p < 0.05$; ** $p < 0.01$; *** $p < 0.001$.

Univariate Analysis of Treatment Effects

Figure 1 and Table 1 provide an overview of the share of participants who made a contribution and the mean contribution amount. The share of subjects who contributed to carbon removal was larger than zero in both treatments (t-test, p = 0.000). Sixty-five percent of all subjects contributed a positive amount to the public good. In S, 70% of subjects gave a positive amount; this share decreased to 60.9% in CBS. As Figure 1 shows, this decrease is not statistically significant at any conventional level (exact Fisher's test, p = 0.25). We can thus reject the null hypothesis (H_0: WTPS = 0) of our first hypothesis.

We continue with the subjects' implicit WTP for carbon removal. Considering only those who donated, the mean WTP does not differ significantly between S and CBS (€10.28 in S vs. €9.21 in CBS; t-test, p = 0.420). In relative terms, the average contributions amount to 51.2% (S) and 46.0% (CBS) of the fixed payment amount. Including all observations, the mean WTP amounts to €6.33 per 100 kg of annual removal. In the S treatment, the mean WTP is €7.18/100 kg. It is €5.61/100 kg in the CBS treatment. The difference in means is not significant (t-test, p = 0.166). The regression analysis (Figure 1b) confirms that highlighting local co-benefits in CBS has no significant effect.[16] Controlling for the quality of

Figure 1
Extensive and Intensive Margin Effects by Treatments: (a) Average Amount of Contributions (€); (b) Amount of Positive Contributions (€) (Intensive Margin); (c) Share of Subjects Willing to Make a Positive Contribution (Extensive Margin)



Note: S treatment = information about the role of trees in carbon sequestration; CBS treatment = information about the local benefits of trees in addition to their carbon sequestration potential.

a related topic (but with another subject pool) and jointly forwarded to the German National Garden Show such that in total four trees were planted. In contrast to other tree-planting initiatives, we did not plant saplings. According to the project initiators, planting more mature trees is more efficient. Such trees are more resilient and have a g chance of survival. The Caucasian wingnut ultimately grows to a height of about 25 m.

[16] Appendix Table B9 runs the model specifications over the whole sample and finds no differences between treatments.

participants' spatial environment, we find no impact on contribution behavior from factors such as forest coverage, availability of other recreational spaces, or urbanization density (see Appendix Table B9).

Thus, we are unable to reject the null hypothesis ($WTP_{CBS} = WTP_S$), and we do not find support for the alternative hypothesis ($WTP_{CBS} > WTP_S$)—we interpret the observed differences in WTP between the two treatments as a null effect in a statistical sense. These data indicate that a shift from a sole focus on carbon removal to a scenario in which local co-benefits are explicitly stressed does not lead to a higher WTP but rather has the countervailing impact of reducing WTP.

When we compare our mean WTP with similar studies in the context of emissions avoidance that facilitated the purchase and retirement of ETS allowances to measure the voluntary WTP for climate mitigation, we infer that WTP for carbon removal through afforestation appears to be substantially higher than WTP for emission avoidance thorough ETS allowance cancellation in Germany. Löschel, Sturm, and Vogt (2013) find a mean WTP of €1.2/100 kg CO_2, while Diederich and Goeschl (2014) estimate a mean WTP of €0.60/100 kg CO_2. The reasons for this may be manifold. First, these studies were conducted several years ago such that these differences might simply reflect differences in preferences for climate protection. Second, the ETS is a highly effective but complex market-based mitigation measure that may not be easily understandable and thus appears comparatively inaccessible to a layperson. On the other hand, afforestation as a mitigation measure is a simple and visible approach. The extent to which such underlying motives drive differences in WTP is discussed in Section 5 and is based on postexperimental survey evidence.

Relationship between WTP and Distance

Data on participant location allow us to investigate whether an individual's distance from the forest carbon sink matters at the extensive or intensive margins. The mean subject distance from the sink was 320 km. The closest subject lived 1.7 km from the afforestation project, and the farthest was 811.8 km. Looking at the distribution of subjects across Germany (Appendix Figure B1), we see that participants are spread across the country, with most living rather far away (median: 302 km). For our analysis, we used a measure based on car travel time in minutes from a subject's location to the afforestation project. For the regression analysis, we subdivided the results of this measure into four distributional quartiles. We ultimately find a weak link between travel distance and the likelihood of contributing to the project (Figure 2, right; Table 2). Because of the lower number of participants located close to the project, we could not run a full regression analysis to identify potential correlation between our treatments and distance, as set forth in our third hypothesis. A descriptive approach (see Appendix Figure B2) indicates there might be some difference in propensity to donate as a function of distance.

Accordingly, we can only partially reject our third hypothesis. Averaged over both treatments, we find a correlation between donation and distance at the extensive margin, but we do not find an impact of distance on the donation amount.

5. Understanding Potential Ex Ante Priors

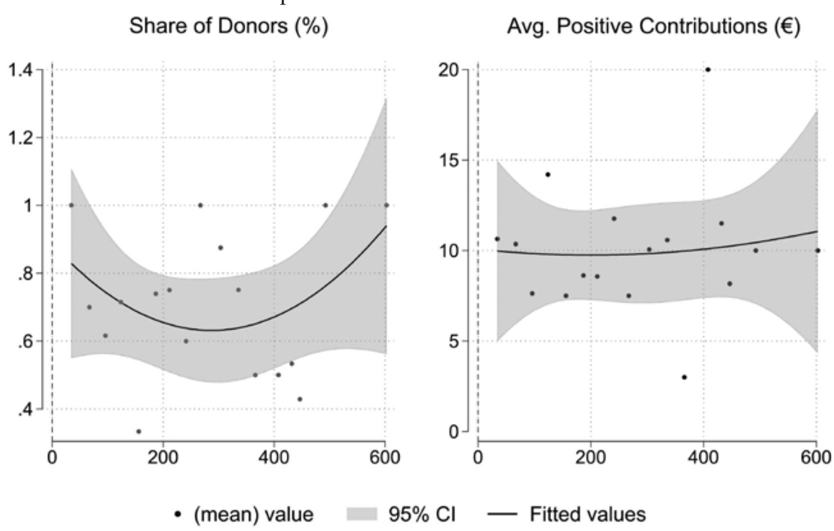
In contrast to expectations, our experimental results do not show an increased WTP when co-benefits are emphasized. We conjecture that this stems from nonobserved, ex ante prior beliefs held by subjects. Especially in the CBS treatment, an individual's responsiveness to additional information may depend on prior knowledge and beliefs. Accordingly, when subjects are already aware of co-benefits, highlighting them may not have the intended effect. Baranzini, Borzykowski, and Carattini (2018) find a similar effect in their study: subjects already took local benefits into account, causing that study's local co-benefits treatment to be noneffective. The supposition of this causal mechanism is reasonable in our setting, as the planting of trees has become a popular and widely discussed proenvironmental measure in Germany.

Table 2
Relationship between Distance to Sink in Minutes and Main Outcomes

	Hurdle	
	First Stage	Second Stage
Treatment: co-benefits	–0.17 (0.24)	–1.12 (2.32)
Age	–0.01 (0.01)	0.17* (0.07)
Female	–0.22 (0.26)	–2.19 (2.88)
Time	–0.05 (0.04)	–0.37 (0.41)
Risk	0.04 (0.06)	0.80 (0.62)
Paternalism	–0.08 (0.05)	–0.54 (0.56)
Trust	0.06 (0.05)	0.31 (0.51)
Complexity	0.03 (0.05)	–0.19 (0.44)
Forest coverage	0.00 (0.03)	–0.23 (0.23)
Recreational space	0.04 (0.11)	–1.61 (1.02)
Agricultural space	–0.01 (0.03)	–0.34 (0.25)
Rurality	–0.02 (0.01)	–0.14 (0.14)
Wind energy	0.00 (0.00)	0.00 (0.00)
Habitat density	0.00+ (0.00)	0.00 (0.00)
Distance category (travel time)		
First quartile (0–137.2 min)	—	—
Second quartile (137.3–197.1 min)	–1.12* (0.46)	–1.76 (4.52)
Third quartile (197.2–329.5 min)	–0.19 (0.42)	0.56 (4.06)
Fourth quartile (329.6–602.6 min)	–0.69 (0.46)	4.19 (5.04)
Constant	3.06 (2.67)	27.81 (22.03)
Constant hurdle	2.05*** (0.13)	
Observations	148	148

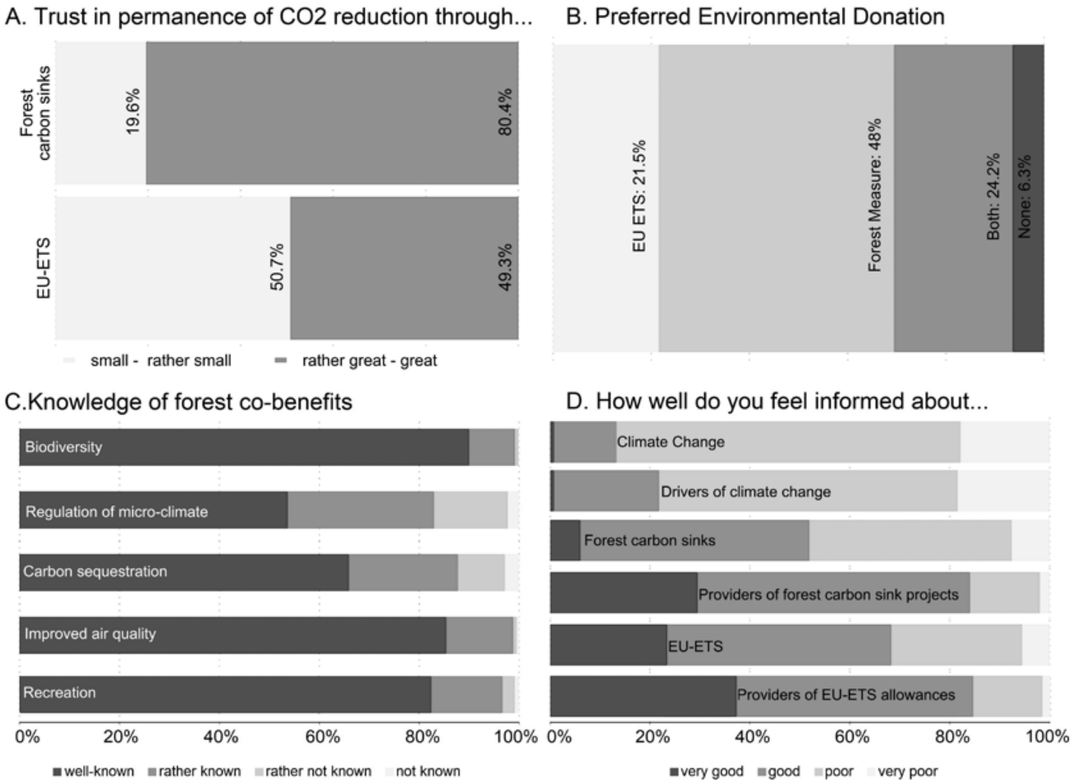
Note: The table entails a regression analysis based on two-stage hurdle models. The first stage consists of probit regression models (where the dependent variable is equal to one for positive donations and zero otherwise). The second stage consists of truncated linear regression models (where the continuous dependent variable is the donation amount, assuming donation is made). Co-benefits indicate the treatment variation that introduces the additional information on co-benefits. Robust standard errors are in parentheses.
+ $p < 0.10$; * $p < 0.05$; ** $p < 0.01$; *** $p < 0.001$.

Figure 2
Relationship between Distance and Main Outcomes



Note: The figure shows the descriptive analysis of distance to the carbon sink measured in travel minutes by car (*x*-axis) on the donor share and the average conditional donations to the afforestation project.

Figure 3
Survey Results



Note: See Appendix Tables C2 and C3 for a detailed explanation of the variables.

Owing to the design of our experiment, we were unable to include questions that would have elicited information about participants' prior knowledge and beliefs regarding local forest sinks. However, to gain some level of insight into possible priors, we conducted an additional survey of students at the University of Münster. In this survey, we assessed knowledge about and general attitudes toward donating to carbon-offsetting initiatives (ETS, tree planting) and knowledge of forest co-benefits (see Appendix C for the survey). The university's Online Recruitment System for Economic Experiments was used to recruit subjects; 567 students participated. We are aware that this survey cannot perfectly substitute for the missing information in our experimental design, but we believe the results provide meaningful additional insights (Figure 3).

First, we replicated the donation question in our experiment but framed it hypothetically. This hypothetical framing produced almost identical values, with a mean WTP_{hyp} of €6.7 (vs. a $WTP_{revealed}$ of €6.3) and a median WTP_{hyp} of €5 (vs. a $WTP_{revealed}$ of €4.6). We are therefore confident that insights from this supplemental survey are informative for a better understanding of the ex ante beliefs in our experiment.

Second, the results from this second survey coincide with our experimental finding that the public valuation of forest carbon sinks appears to be higher than that of ETS allowance purchase and withdrawal. When subjects were asked about their preferred form of donation, 48% preferred carbon removal through forests and 22% preferred emission avoidance through ETS allowances. To investigate the potential reasons for such preferences, we asked subjects how much they trusted in the long-term effectiveness of carbon removal through forests and emission allowances. We found low trust in the long-term effectiveness of ETS allowances (45% indicated "moderately high" to "high" trust) but high trust in carbon removal through forest (80% indicated "moderately high" to "high" trust). This is in contrast to the policy dimension of emissions avoidance being the key climate policy tool, with carbon removal only serving as a complementary tool.

Third, we asked subjects about their knowledge of forest co-benefits and found that they seemed to be well informed about all questioned co-benefits. This accords with our supposition that experimental subjects have prior knowledge of co-benefits, thus causing dedicated notification of co-benefits to be not effective. When we investigated subject knowledge of the ETS and afforestation forest measures, most indicated a low level of knowledge about the former but felt more informed about the latter.

Transferring this to our experimental results, the survey evidence supports the notion of a limited understanding of the abstract and complex ETS structures, resulting in a restricted trust in this measure as mitigation avoidance tool. In contrast, many publicity campaigns in recent years have highlighted the value of tree-planting projects as one way to reduce climate change in Germany. This publicity may be the underlying reason for a higher level of knowledge about, and support for, forest measures, as observed in our experimental results.

6. Discussion and Conclusion

Although emission avoidance will necessarily remain the predominant component of the global effort to fight climate change, increased attention is being paid to CDR technologies as a way to counterbalance hard-to-abate residual emissions. In this article, we estimated individual WTP for afforestation-based carbon removal using a revealed-preferences approach.

We find that people, on average, have a substantial WTP and give about 50% of their fixed payment amount to support afforestation-based carbon removal. We hypothesized that local co-benefits are one possible driver of this willingness and tested how highlighting such benefits affects participant WTP. In our setting, we find no impact on revealed WTP of highlighting such benefits compared with a setting in which co-benefits are left unmentioned. One explanation for this could be the nonobserved ex ante priors of our subjects. We were not able to control for such ex ante priors in our experimental sample. Accordingly, we conducted an additional survey of students, which confirm existing knowledge of co-benefits. Although the results of the student sample are not necessarily generalizable to the broader population, they provide valuable suggestive evidence and open the field for additional research. Last, we find weak evidence of a distance-decay effect. With increasing distance to the afforestation project, the likelihood to contribute to it decreases. It should be noted, however, that the weak distance-decay effect would be of little surprise if participants considered contributing to the municipal tree-planting project exclusively as a contribution to a public good. This is an important insight for designing contribution appeals for such programs.

We compare the insights from our study with previous studies that investigate WTP for individual climate mitigation through voluntary contributions to mitigation avoidance. CO_2 emission avoidance is directed toward the source of emissions and is facilitated through ETS, which is a well-established system. WTP ascertained by our study diverges considerably from that of other studies on WTP for avoidance that were, admittedly, carried out some time ago. For Germany, Löschel, Sturm, and Vogt (2013) report a mean WTP of €12/tCO_2, and Diederich and Goeschl (2014) report a mean WTP of €6/tCO_2. Both studies report a close to zero median WTP. Assuming linearity in marginal WTP, our results indicate a median WTP of €46/tCO_2 and a mean WTP of €63.3/tCO_2. Despite these comparably high estimates for forestry-based CDR measures, it can be questioned whether this indeed yields an efficient mitigation approach. Generally, forestry-based CDR measures are widely acknowledged for their low-cost potential, especially as the marginal costs of establishing carbon sinks can be considerably lower than those of carbon avoidance (Richards and

Stokes 2004; van Kooten et al. 2004; Gren and Aklilu 2016; van Kooten 2017). However, cost calculations exhibit considerable variation,[17] and a metaregression analysis by van Kooten et al. (2004) finds that the costs of forest carbon sequestration range between US$12.7 and US$70.9 per ton of CO_2. Unlike other afforestation initiatives, we did not plant samplings, and the planting costs included long-term maintenance to ensure longevity and eventually a high carbon uptake potential. Consequently, the cost of carbon sequestration in our setting is assumed to be higher compared with the estimates provided by van Kooten et al. (2004).

Still, our study finds that the population attaches higher value to forest-based carbon removal than to ETS-based emissions avoidance. Our supplementary survey of students corroborates these results. Subjects feel better informed about, and have higher trust in, forest measures than ETS-based avoidance. This finding accords with Gregory, Satterfield, and Hasell (2016) and Wenger, Stauffacher, and Dallo (2021). The latter study reports that Swiss citizens are familiar with afforestation, and that afforestation enjoys a strong reputation and support. At the same time, knowledge of emissions trading (cap-and-trade) systems compared with other policies appears to be small, even though the system was established over a decade ago (Dabla-Norris et al. 2023). Rhodes, Axsen, and Jaccard (2017) investigate public policy support for different climate policy types in Canada, finding that among the array of available climate policies, support for market-based instruments, such as a cap-and-trade system, is very low, whereas support for regulatory and voluntary policies is comparatively high. Given the empirical evidence from 29 European countries on the importance of public trust for effective climate action (Carattini, Baranzini, and Roca 2015), there is clearly a need for remedial action in this area.

These observations should be taken into consideration by policy makers as they consider future emission avoidance and removal measures. To be sure, avoidance and decarbonization must remain the primary vehicles for mitigation. While forest carbon sinks are considered to have a large potential to support climate stabilization (Lewis et al. 2019; Austin et al. 2020; Cook-Patton et al. 2020; Forster et al. 2021), they are not a panacea in the fight against climate change.

Tree-based carbon removal is considered relatively risky because the carbon sequestration is reversible through deforestation or natural disturbances. Further uncertainties pertain to land availability and suitability as well as to interactions with other ecosystem services. The inherent complexity of ecological processes and controversies surrounding the development-versus-conservation conflict further exacerbates the difficulty of incorporating forest measures into official programs to mitigate climate change, especially because the long-term carbon-storage capacity of forests is uncertain because carbon sequestration is reversible (Maréchal and Hecq 2006). Consequently, experts view forest carbon sinks as a supplemental (but not primary) means of addressing climate change to avoidance measures with a potential to especially decrease levels of peak warming (Matthews et al. 2022).

Our findings thus suggest that there is a gap between public and expert assessments of options for climate action and their technical feasibility. Against this backdrop, there is a need to consider the interrelationships between avoidance and removal, including related trade-offs. Recent results from earth system modeling suggest that CO_2 avoidance is more effective in lowering atmospheric CO_2 concentrations than an equivalent volume of CO_2 removal (Zickfeld et al. 2021). Thus, offsetting positive CO_2 emissions with carbon removal could result in different climate outcomes than an equivalent level of avoidance. A promising path for future research could be to focus on how to correct misperceptions

[17] This variation is explained by varying model assumptions regarding factors, such as the rate of carbon uptake, tree type (deciduous, coniferous), lifetime, climate zone (e.g., tropical or temperate), previous land usage, land suitability, the risks of natural disturbances, the time span, and the final utilization of timber and wood products (Bateman and Lovett 2000; Núñez, Nahuelhual, and Oyarzún 2006; van der Horst 2006; Canadell and Raupach 2008; Profft et al. 2009; Ninan and Inoue 2013; Forster et al. 2021). When also considering factors such as the opportunity costs of land, the average costs rise significantly (van Kooten et al. 2004).

among consumers regarding the different mitigation options. Developing a more detailed understanding of how individual distance from an afforestation project affects donation behavior; taking land use and availability into account also appears advisable. For example, the EU Regulation on Land Use, Forestry, and Agriculture obliges member states to establish natural carbon sinks equivalent to 310 million tons of CO_2 by 2030. Future research would thus be advised to consider the potential trade-offs of newly established forest carbon sinks with other ecosystem services owing to potential land use change and take into account concerns regarding permanence, additionality, leakage, and feasibility as well as the cost of monitoring, measuring, and maintaining such sinks (Gren and Aklilu 2016; van Kooten and Johnston 2016; Gifford 2020; Shrestha et al. 2022). Such research would also benefit from interdisciplinary studies between, for example, the fields of biology, psychology, and economics (Fuss et al. 2020). We thus hope that our study motivates additional research on environmental donations, particularly in the context of voluntary (land-based) carbon removal activities, and considers both co-benefits and associated trade-offs.

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