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

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Abstract: This study explores the 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 removal. Emphasizing co-benefits doesn't 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.

1. Introduction

While emission avoidance strategies such as the development of low-carbon technologies, the rapid expansion of renewable energy sources, 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 suffice to reach net zero GHG emission targets (Fekete et al. 2021; Lawrence et al. 2018; Nieto, Carpintero, and Miguel 2018). Attention is therefore increasingly being paid to climate change mitigation though emission removal 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 IPCC scenarios that limit global warming to 2°C (IPCC 2022; Smith et al. 2023). Among available CDR[1] methods, establishing forest carbon sinks is one of the few measures for which large-scale CDR may be possible at present (IPCC 2022). 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) and to decrease peak warming over the short- to mid-term (Matthews et al. 2022). They are acknowledged for their cost-effectiveness, with lower marginal cost[2] when compared to emissions avoidance measures (Richards and Stokes 2004; van Kooten et al. 2004; Gren and Aklilu 2016; van Kooten 2017). In addition, they provide valuable co-benefits[3], including recreation, timber, biodiversity, improved air quality and natural regulation of atmospheric temperature, soil protection, and hydrologic functions.

Consequently, establishing forest carbon sinks, e.g. through afforestation or reforestation[4] has been garnering increased political and public attention, and account for about 99% of currently deployed CDR land measures (Smith 2023).[5] Forest carbon sinks were a subject of keen discussion at COP27 or within the EU Forest Strategy for 2030, which commits EU member states to reverse forest loss and pledged to increase forest coverage. However,

47 increasing the tree coverage of land is complex. On the one hand, land-use conflicts may arise
48 because the land used for planting trees can serve multiple purposes and creating new spaces
49 for forest carbon sinks may encounter public resistance (Holl and Brancalion 2020). On the
50 other hand, the valuation for forest carbon sinks as a mitigation measure might depend on, and
51 be positively influenced by, the potential co-benefits of such carbon sinks. This is particularly
52 true for the highly palpable forest co-benefits[6].

53 With the shift toward actively integrating forest carbon sinks into climate policies, there
54 is a need to develop a comprehensive understanding of public preferences in this regard, and
55 how markets and individuals value carbon sinks (Holl and Brancalion 2020; Shrestha et al.
56 2021).

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

69 For this purpose, we provide a first incentivized framed field experiment to elicit revealed
70 WTP for forestry-based carbon removal in a broader German-wide population sample. In our
71 experiment, study participants are randomly divided in two groups and are asked to give up real

money to support a local afforestation project and thus remove CO_2. For the control group, the contribution decision is neutrally framed and describes the need for carbon removal as a climate mitigation activity, the carbon sequestration potential of trees, and provides a description of the afforestation project. In the treatment group, we provide the same information as in the control group, but additionally highlight the local co-benefits of the afforestation project. To understand whether participants exhibit different valuations for forest carbon sinks and their co-benefits based on spatial variations, we utilize a Germany-wide sample and leverage the availability of the geographical position of each subject. This enables us to construct a distance measure, allowing investigation into the distance-decay effect on our reveled WTP. Furthermore, we use the geographical dispersion of participants to add and control for heterogeneous geo-data (e.g. forest coverage, urbanization level) to assess whether the WTP is influenced by factors such as varying densities of already existing forest coverage. To augment our framed field experiment, we conducted an additional survey among 567 students to shed more light on general attitudes towards and knowledge about carbon removal and avoidance.

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

Our findings contribute to the growing literature to the public's perception and acceptability of natural CDR methods in general (Wolske et al. 2019; Cox et al. 2020; Bellamy 2022; Merk et al. 2023) and in particular 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 policymakers to "design financial incentives […] that target the conservation of forests to preserve the otherwise non-marketed ecosystem services that they provide" (Taye et al. 2021, p.2). Previous studies typically evaluate people's willingness 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 predominately driven by preferences for local co-benefits (Löschel et al. 2021).

However, so far it 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. Our study contributes to closing this gap. Compared to climate contributions made through the ETSs, 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 that these co-benefits are valued positively (Rodríguez-Entrena et al. 2014; Torres et al. 2015)[7]. Evidence based on revealed-preference methods, is however, scarce. To the best of our knowledge, Baranzini et al. (2018) is the only revealed preference study that investigates voluntary contributions to a reforestation project to offset carbon emissions (through supporting both national and

121 international forest projects) in a lab setting with a student sample, and also investigates the
122 impact of co-benefits at the intensive margin as they investigate how the co-benefits
123 information influence how participants split an already determined amount between a national
124 and an international project. Our study, in contrast, uses a field experimental approach to reveal
125 the WTP for national forestry-based carbon removal in a broader population sample and
126 evaluate the impact of co-benefits on the willingness to contribute to the public good both at
127 the extensive and intensive margin.

128 ## 2. Methods

129 ### 2.1 Framed Field Experiment

130 Our framed field experiment was conducted between 16 and 25 March 2020. It was
131 attached to an online survey that was conducted jointly with the University of Münster and a
132 German online price comparison website[8] that allows customers to compare the electricity
133 service plans offered by different providers. Personalized survey invitations were sent via email
134 to the platform's registered users, who stem from the general population. The invitation
135 included information on the purpose of the survey and the time required to complete it. It also
136 explained that participants would receive a fixed payment of €20 for completion, as well as an
137 additional variable payment between €6 and €40, depending on their answers to the survey. The
138 final payment was paid out through a voucher redeemable at over 500 stores. The survey was
139 thematically unrelated to our experiment and investigated consumer behavior in the retail
140 electricity market. Our experiment was placed at the very end of this survey. Participants were
141 not aware of the actual experiment, in which we scrutinized their propensity to contribute to
142 environmental protection under two different treatments.

143 In our survey design, we introduced a donation option as an experimental variation on the
144 conventional financial reward for participating in a survey. Due to our design, we were unable
145 to collect post-experimental data, e.g. on individual beliefs and motivations. Rather, we were

146 only able to collect standard economic preferences [9] in addition to the age, gender, and
147 geographical location of each participant. We acknowledge that the subjects' location during
148 survey participation was not necessarily identical to their place of residence. However, the
149 survey took place at the beginning of the German COVID lockdowns. Childcare facilities and
150 schools were closed; remote work was encouraged; and public life was reduced. These factors
151 increased the chance that participants were located at home.

152 After subjects completed the survey, we informed them that they could support an
153 afforestation project by making a donation from the fixed share [10] of their payment for
154 participating. To implement a real donation, we collaborated with the City of Mannheim, which
155 is hosting the National Garden Show[11] in 2023. For the event, a disused military base is being
156 transformed into green areas, and approximately 1,000 trees will be planted, thus creating an
157 additional local carbon sink. Subjects were asked how much they would be willing to donate to
158 the afforestation project, given 100 kg of CO_2 removal from the atmosphere.[12]

159 We also introduced a treatment that addressed co-benefits. The survey program randomly
160 divided subjects into two groups: namely, the sink (*S*) and the co-benefit (*CBS*) treatments. In
161 both treatments, subjects received relevant information on the need for global climate
162 protection. This ensured that each participant had the same basic knowledge regarding climate
163 change and the role played by trees in climate-change mitigation efforts. In particular, we
164 explained the role of forest carbon sinks in climate protection, and gave subjects information
165 on the average CO_2 absorption capacities of trees using the example of a beech tree, which, on
166 average, absorbs 100 kg of CO_2 over eight years (Klein 2009). To make this information more
167 accessible, we explained that 100 kg of CO_2 is approximately equal the emissions caused by a
168 550 km car trip. Finally, we gave subjects information on the local afforestation project, and
169 explained their donation would be used to plant additional trees. In the *CBS*-treatment, by
170 contrast, we additionally included information on local co-benefits. Specifically, we highlighted

171 the project's advantages in terms of recreational opportunities, improved local air quality, the
172 regulation of local atmospheric temperature, and greater biodiversity (see Appendix Table A2
173 and Appendix A.2 for an overview and detailed information). Only after receiving this
174 information were subjects asked to indicate their WTP. The likelihood of making a donation
175 (extensive margin effect) and the amount donated (intensive margin effect) were the main
176 outcome variables for our analysis.

177 ## 2.2 Observational Data on Location

178 The attitude shown by participants towards the afforestation project may be affected by
179 the distance-decay effect and the subjects' geographic locations. Past research has shown that
180 WTP is affected by the accessibility of substitutes (e.g. other forested areas); Czajkowski et al.
181 (2017), for example, find that WTP is higher when surrounding forests are scarce. To control
182 for this, we match our experimental data with geo-data from the INKAR database (BBSR Bonn
183 2020) maintained by the German Federal Office for Building and Regional Planning. Most
184 indicators have been collected on a continuous basis since 1995 and are granular to the district
185 level. For our analysis, we draw on indicators of forest coverage, installed wind energy capacity,
186 volume of recreational and agricultural space, urbanization level, and habitat density.

187 # 3. Literature and Hypotheses

188 As the individual costs that accrue from conservation efforts typically outweigh the
189 individual benefits that can be expected to arise from increased environmental quality, strong
190 free-riding incentives are expected to prevent contributions to global public goods such as GHG
191 mitigation. However, vast experimental evidence demonstrates that individuals do contribute
192 privately to public goods (see e.g. Ledyard 1995 and Chaudhuri 2011 for comprehensive
193 literature reviews). This finding has been confirmed in studies estimating WTP for emission
194 avoidance. In such studies, subjects are asked whether and/or how much they would pay to

prevent emissions, based on the purchase and withdrawal of emission allowances from an emissions trading scheme, 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).

With the increasing recognition that establishing forest carbon sinks is a promising supplementary path in climate change mitigation efforts, 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. So far, it remains an open question as to whether the empirical insights developed regarding individual emission avoidance 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 (CE) 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; 2014) use data from the same CE 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 CE to estimate the 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 (CVM) to measure the WTP for the carbon sequestration service of forests in Turkey. They find a WTP of €0.07/tCO_2.

Baranzini et al. (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, approx. 6 euros) of their average endowment (7 CHF, approx. 7 euros).

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 the standard assumptions regarding the voluntary provision of public goods. Our first statistical hypothesis on WTP to contribute to carbon removal in the S treatment (WTP_S) thus reads as follows:

Hypothesis H1 $H_0: WTP_S = 0$ $H_A: WTP_S > 0$

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). Past 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 the highlighting of 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 rather 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 report (2022) 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,[13] studies estimating the impact of co-benefits on WTP for carbon removal are rare. 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 et al. (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 within a municipality project affect revealed WTP remains an open question.

To the best of our knowledge, Baranzini et al. (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 to an international (Nicaragua) program. In contrast to our setting, they use a lab experiment with a student sample, while we utilize a general population sample. Additionally, 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, if so, how much money they want to allocate to the purchase of carbon offsets. Only then the treatments, i.e. information on the co-benefits of the domestic program are 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 et al. (2018) only measure the extent to which co-benefits information influences the allocation decision between the two options. In contrast, we can investigate whether co-benefits information has an impact on both the propensity to give and the amount given in our setting.

We expect contributions to be higher when the local benefits of afforestation are stressed compared to a setting in which they are not stressed (i.e. $WTP_{CBS} > WTP_{S}$). 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 thus remains an open question. Accordingly, we formulate our second hypothesis (H2) as follows:

Hypothesis H2 H_0: $WTP_{CBS} = WTP_S$ H_A: $WTP_{CBS} > WTP_S$

While 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 ES studies we know that the (stated) valuation of goods and services is subject to a distance-decay function (Bakhtiari et al. 2018; Bateman et al. 2006; Del Saz Salazar and García Menéndez 2007; Schaafsma et al. 2013). 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 within a close distance 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 non-use 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 predominately 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 anticipate a difference between those who are located close to

the afforestation project and those who are located further away. If this holds true, we can reject the null hypothesis (H_0: $\rho(WTP,c)=0$) in our H3 hypothesis, which captures the correlation ρ between the spatial proximity c to the afforestation project and WTP as follows:

Hypothesis H3 H_0: $\rho(WTP, c) = 0$ H_A: $\rho(WTP,c) > 0$

4. Results

We sent out 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 very end. A total of 359 subjects started the survey, and 160 completed it.[14] The median time participants spent answering the survey was 10.99 minutes (p10 = 4.5 minutes, p90 = 40 minutes).[15] 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, while the *CBS* treatment has 87. Balance tests on age and gender found a balanced sample. Appendix B provides a description of experimental (refer to Appendix Table B1 – B5) and geographical (Appendix Table B6 – B8) variables. In total, the subjects donated 1,797 euros, which was used to plant 2.5[16] Caucasian wingnut trees of five to six meters in height[17] in May of 2021.

4.1 Univariate Analysis of Treatment Effects

Figure 2 provides 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). 65.0% of all subjects contributed a positive amount to the public good. In *S*, 70.0% of all 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 (H0: WTPS= 0) of our first hypothesis.

We continue with the subjects' implicit WTP for carbon removal. Considering only those who donated, mean WTP does not differ significantly between *S* and *CBS* (10.28 euros in *S* vs. 9.21 euros 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 euros per 100 kg of annual removal. In the *S*-treatment, the mean WTP is 7.18 euros/100 kg. In the *CBS* it is 5.61 euros/100 kg. The difference in means is not significantly different (t-test, p=0.166). The regression analysis (refer to panel B of Figure 1) confirms that highlighting local co-benefits in *CBS* has no significant effect.[18] Additionally controlling for the quality of participants' spatial environment, we find no impact on contribution behavior from factors such as forest coverage, availability of other recreational spaces, or urbanization density (refer to Supplementary Table B.9).

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 – if anything – has the countervailing impact of reducing WTP.

When we compare our mean WTP to similar studies in the context of emissions avoidance, that facilitated the purchase and retirement of EU ETS allowances to measure the voluntary WTP for climate mitigation, we infer that the WTP for carbon removal through afforestation appears to be substantially higher than the WTP for emission avoidance thorough EU ETS allowance cancellation in Germany. Löschel, Sturm, and Vogt (2013) found a mean WTP of 1.2 euros/100kg CO_2 while Diederich and Goeschl (2014) estimated a mean WTP of

343 0.60 euros/100kg CO_2. Reasons for this may be manifold. First, these studies have been
344 conducted several years ago such that these differences might simply reflect differences in
345 preferences for climate protection. Second, the EU ETS is a highly effective but complex
346 market-based mitigation measure that may not be easily understandable and, thus, appears
347 comparatively inaccessible to laypersons. On the other hand, afforestation, as a mitigation
348 measure, is a simple and visible approach. The extent to which such underlying motives drive
349 the differences in the WTPs is discussed in Section 5 based on post-experimental survey
350 evidence.

351 *[Insert Figure 1 here] [Insert Table 1 here]*

352 Figure 1 Extensive and intensive margin effects by treatments

353 **4.2 Relationship between WTP and Distance**

354 Data on participant location allows us to investigate whether the individual's distance
355 from the forest carbon sink matters at the extensive or intensive margin. Mean subject distance
356 from the sink was 320 km. The closest subject lived 1.7 km and the farthest 811.8 km away
357 from the afforestation project. Looking at the distribution of subjects across Germany (see
358 Appendix Figure B1), we see that participants are spread across Germany, with most subjects
359 living rather far away (median: 302 km). For our analysis, we use a measure that is based on
360 car travel time in minutes from the subject's location to the afforestation project. For the
361 regression analysis, we subdivide the results of this measure into four distributional quartiles.
362 We ultimately find a weak link between travel distance and the likelihood of contributing to the
363 project (see Fig. 2, panel B). Due to the lower number of participants located close to the project,
364 we cannot run a full regression analysis to identify potential correlation between our treatments
365 and distance, as set forth in our third hypothesis. A descriptive approach (see Appendix Figure
366 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.

[Insert Figure 2 here] [Insert Table 2 here]

Figure 2 Descriptive relationship between distance to sink in minutes and main outcomes

5. Understanding Potential Ex-Ante Priors

In contrast to expectations, our experimental results do not show increased WTP when co-benefits are emphasized. We conjecture that this stems from non-observed, ex-ante prior beliefs held by subjects. Especially in the *CBS* treatment, the individual's responsiveness to additional information may depend on his or her prior knowledge and beliefs. Accordingly, when subjects are already aware of co-benefits, highlighting them may not have the intended effect. Baranzini et al. (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 non-effective. The supposition of this causal mechanism is reasonable in our setting, as the planting of trees has become a popular and widely discussed pro-environmental measure in Germany.

Due 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, in order 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 (EU-ETS; tree planting), as well as 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 (see Fig 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 euros (vs. a $WTP_{revealed}$ of 6.3 euros) and a median WTP_{hyp} of 5 euros (vs. a $WTP_{revealed}$ of 4.6 euros). 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 our second survey coincide with our experimental finding that the public valuation of forest carbon sinks appears to be higher than that of EU ETS allowance purchase and withdrawal. When asking subjects for their preferred form of donation, 48% of subjects preferred carbon removal through forests and 22% preferred emission avoidance through EU-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 find low trust in the long-term effectiveness of EU 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.

[Insert Figure 3 here]

Figure 3 Survey results

Third, we asked subjects about their knowledge of forest co-benefits and found that subjects seemed to be well informed about all questioned co-benefits. This finding accords with our supposition that experimental subjects possess prior knowledge of co-benefits, thus causing dedicated notification of co-benefits to be non-impactful. When we investigated subject

knowledge of the EU ETS and afforestation forest measures, most subjects indicated a low level of knowledge about EU ETS, but felt much more informed about forest measures.

Transferring this back to our experimental results, the survey evidence indeed supports the notion of a limited understanding on the abstract and complex EU ETS structures, resulting in a restricted trust in this measure as mitigation avoidance tool. In contrast, numerous publicity campaigns in recent years have highlighted the value of tree-planting projects as a means of preventing 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

While 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 means of counterbalances hard-to-abate residual emissions. In this paper, we estimated individual WTP for afforestation-based carbon removal using a revealed preferences approach.

We do 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 impacts participant WTP. In our setting, we find no impact on revealed WTP of highlighting such benefits, compared to a setting in which co-benefits are left unmentioned. One explanation for this could be the non-observed 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 confirmed existing high knowledge of co-benefits. While 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. Lastly, 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 contributions to the municipal tree-plant project exclusively as a contribution to a public good. This is an important insight for designing contribution appeals for such programs.

We use the insights from our study to mirror them against previous studies that investigates the WTP for individual climate mitigation through voluntary contributions to mitigation avoidance. CO_2 emission avoidance is directed towards the source of emissions and is facilitated through Emission Trading Systems (ETS), which is a well-established system. The WTP ascertained by our study diverges considerably from that of other studies on the WTP for avoidance that where – admittedly – carried out some time ago. For Germany, Löschel, Sturm, and Vogt (2013) report a mean WTP of 12 euros/tCO_2, while Diederich and Goeschl (2014) report a mean WTP of 6 euros/tCO_2. Both studies report a close to zero median WTP. Assuming linearity in marginal WTP, our results indicate a median WTP of 46 euros/tCO_2 and a mean WTP of 63.3 euros/tCO_2. Despite these comparably high estimates for forestry-based CDR measures, it can be called into question 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[19] and a meta-regression analysis by van Kooten et al. (2004) finds that the costs of forest carbon sequestration range between US $12.7 and $70.9 per ton of CO_2. Unlike other afforestation initiatives, in our study we did not plant samplings and the planting costs included an assurance of 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 to 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 et al. (2016) and Wenger, Stauffacher, and Dallo (2021). The latter study reports that Swiss citizens are very familiar with afforestation, and that afforestation enjoys a strong reputation and strong 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 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 policymakers as they consider future emission avoidance and removal measures. To be sure, avoidance and decarbonization must remain the primary vehicles for mitigation. And 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 no panacea in the fight against climate change.

Tree based carbon removal is considered relatively risky, as the carbon sequestration is reversible through deforestation or natural disturbances. Further uncertainties pertain to land availability and suitability as well as interactions with other ecosystem services. The inherent complexity of ecological processes and controversies surrounding development-versus-

490 conservation conflict further exacerbate the difficulty of incorporating forest measures into
491 official programs to mitigate climate change. Especially as the long-term carbon-storage
492 capacity of forests is uncertain, as carbon sequestration is reversible, e.g. through deforestation
493 or natural disturbances (Maréchal and Hecq 2006). Consequently, experts view forest carbon
494 sinks as a supplemental (but not primary) means of addressing climate change to avoidance
495 measures with a potential to especially decrease levels of peak warming (Matthews et al. 2022).

496 Our findings thus suggest that there is a gap between public and expert assessments of
497 options for climate action and their technical feasibility. Against this backdrop, there is a need
498 to consider the interrelationships between avoidance and removal, including related tradeoffs.
499 Recent results from earth system modeling suggest that CO_2 avoidance is more effective in
500 lowering atmospheric CO_2 concentrations than an equivalent volume of CO_2 removal (Zickfeld
501 et al. 2021). Thus, offsetting positive CO_2 emissions with carbon removal could result in
502 different climate outcomes than an equivalent level of avoidance. A promising path for future
503 research could be to focus on how to correct misperceptions among consumers regarding the
504 different mitigation options. Developing a more detailed understanding of how individual
505 distance from an afforestation project affects donation behavior while also taking land use and
506 availability into account appears advisable too. For example, the EU Regulation on Land Use,
507 Forestry, and Agriculture obliges member states to establish natural carbon sinks equivalent to
508 310 million tons of CO_2 by 2030. Future research would thus be advised to consider the
509 potential trade-offs of newly established forest carbon sinks with other ES due to potential land-
510 use change, take into account concerns regarding permanence, additionality, leakage, and
511 feasibility, as well as the cost of monitoring, measuring, and maintaining such sinks (Gren and
512 Aklilu 2016; van Kooten and Johnston 2016; Gifford 2020; Shrestha et al. 2021). Such research
513 would also benefit from interdisciplinary studies between the fields of biology, psychology,
514 economics, and others (Fuss et al. 2020). We thus hope that our study motivates additional

515 research on environmental donations, particularly in the context of voluntary (land based)
516 carbon removal activities, while considering not only co-benefits, but also associated trade-offs.

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9. Tables

None

10. Figure Titles

Figure 1: Extensive and intensive margin effects by treatments.

780 **Figure 2:** Relationship between distance and main outcomes

781 **Figure 3:** Survey results

782 ## 11. Grouped Footnotes

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

2 Cost calculations vary considerably, however. According to a meta-regression analysis by van Kooten et al. (2004), the costs of forest carbon sequestration vary between $12.7 and 70.9/tCO2. This is explained by varying model assumptions, e.g. about the rate of carbon uptake, previous land usage, the risks of natural disturbances, the considered time span (Bateman and Lovett 2000; Canadell and Raupach 2008; Ninan and Inoue 2013; Núñez, Nahuelhual, and Oyarzún 2006; van der Horst 2006). Carbon uptake again crucially depends on various factors, including the tree species in question (e.g. indigenous vs. non-indigenous, diversity), tree growth and carbon sequestration rates, the climate zone, land suitability, harvest times, and management (Bastin et al. 2019; Matthews et al. 2022; Neumann et al. 2016; Newell and Stavins 2000; Obersteiner et al. 2018; Pires 2019). In addition, most studies fail to adequately take into account the ongoing costs of maintenance to assure 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 ES that are categorized in terms of use and non-use values (Bateman and Lovett 2000; Canadell and Raupach 2008; Ninan and Inoue 2013; Núñez, Nahuelhual, and Oyarzún 2006; van der Horst 2006). 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. Non-use values include the bequest value, altruist value, and existence value.

3 Co-benefits describe the positive side effects mitigation actions have on other dimensions beyond climate change (IPCC 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 (IPCC 2019). We focus on afforestation, which converts non-forest 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 (BECCS), Direct Air Carbon Capture and Storage (DACCS), biochar, and enhanced rock weathering are expected to be implemented on a large scale over the course of the century (Smith 2023).

6 Forests provide ES that are categorized in terms of use and non-use values (Bateman and Lovett 2000; Canadell and Raupach 2008; Ninan and Inoue 2013; Núñez, Nahuelhual, and Oyarzún 2006; van der Horst 2006). 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. Non-use values include the bequest value, altruist value, and existence value.

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

8 See Appendix A.1 for a detailed description of the sampling procedure and information on the electricity platform.

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

10 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.

11 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.

12 The selected volume of CO2 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 euros/tCO2.

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

14 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 A.3 for a detailed description of the power analysis.

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

16 The donations from this experiment were complemented with donations from another experimental study on 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.

17 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 higher chance of survival. The Caucasian wingnut ultimately grows to a height of about 25m.

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

[19] 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; Canadell and Raupach 2008; Forster et al. 2021; Ninan and Inoue 2013; Núñez, Nahuelhual, and Oyarzún 2006; Profft et al. 2009; van der Horst 2006). When additionally considering factors such as the opportunity costs of land, the average costs rise significantly (van Kooten et al. 2004).