Spatially induced scope effects on willingness to pay for low-carbon energy technologies

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Overview

The pressing challenge of global warming necessitates substantial reductions in CO_2 emissions. The adoption and implementation of innovative low-carbon energy technologies is crucial for reaching net-zero emission targets and mitigating climate change. Carbon capture and storage (CCS) is considered a key technology, with significant potential to reduce emissions from hard-to-abate industries. However, such low-carbon energy technologies vary considerably in their potential to reduce CO2 emissions, and hence, in their relative contribution to climate change mitigation efforts. In Denmark, feasible CO2 storage units offer an estimated annual storage capacity ranging from four to 10 million tons (MT) of CO2, highlighting significant variations in the technology's scope (DEA, 2023).

Additionally, the implementation of such climate mitigation measures often conflicts with existing land uses and other societal interests. As a result, the successful and long-term deployment of CCS critically depends on public perceptions and social support. However, preference formation for novel energy technologies is a complex and comprehensive process involving various prior influential factors (e.g., prior knowledge and personal exposure/experiences with existing energy landscapes), the type and scope of the technology, how it is presented, and the joint interactions thereof.

In this study, we first propose a new behavioral model, capturing multidimensional pathways leading to WTP formation. Specifically, we conceptualize the intricate dynamics between peoples' spatial exposure/experience with existing energy landscape features and their scope sensitivity in evaluating new energy infrastructure projects. The framework builds on the scope classification scheme by Rolfe and Wang (2011), the technology acceptance model by Huijts et al. (2012) and the interlinked impact of information provision (Zuch and Ladenburg, 2023). It explicitly considers the role of spatial factors in mediating scope sensitivity on WTP for energy technologies, distinguishing between three scope domains, i.e., scope, external, and experiential domain.

Based on the proposed behavioral model, we then investigate the interlinkage between scope and spatial effects on peoples' preferences for low-carbon energy technologies. Specifically, the study explores if and to what extent spatial characteristics in peoples' immediate surroundings influence scope sensitivity in WTP for CCS. Focussing on Denamrk, we test how spatial features of the respondents' surrounding environment and energy landscape influence scope effects on WTP for CCS projects (i.e., CCS with varying annual emission reduction capacity of 5Mt vs. 10Mt of CO2). In the analysis, we distinguish between peoples' exposure to CCS-related supplementary energy technologies, i.e., renewables, and complementary energy facilities, i.e., emitting power plants.

Methods

This study is based on stated preference data from a nationally representative survey among Danish households (n = 4,200) to elicit WTP for two different CCS scope scenarios, varying in their annual CO2 reduction capacities. To investigate spatially induced scope effects, we apply a split-sample approach. Respondents were randomly assigned to one of two CCS-specific valuation scenarios: Half of the respondents were presented with a CCS facility, accounting for annual emission reductions of 5Mt of CO2 (5MT sample). The other half was presented with a CCS project with the capacity to reduce emissions by 10 Mt of CO2 per year (10MT sample).

The survey data is combined with detailed geospatial information at the respondent level. We apply spatial analyses to compute respondent-specific exposure and proximity measures regearding existing energy infrastructure and environmental features. The analysis includes data on (a) Denmark's Western coastline, (b) protected forest cover, (c) electrical substations, (d) land-based solar farms, (e) wind turbines, (f) underground gas storage facilities, and (g) emitting energy plants. We then use the precise location of each respondent's residence and geodata on Denmark's national road network to compute respondent-specific 2.5km travel areas, reflecting the household's distance and exposure to existing energy infrastructure and natural amenities.

Based on the obtained survey data and the respondent-specific spatial characteristics, we conduct econometric analyses to investigate scope effects on WTP, following the framework of random utility maximization. To explore and identify spatially-induced scope effects, the statistical model is specified by including interaction terms between the spatial variables and CCS scope (10MT vs. 5MT). This allows to directly assess how spatial factors influence scope effects on CCS WTP.

Results

The results reveal important insights into spatially-induced scope effects on willingness to pay (WTP) for carbon capture and storage (CCS). While we find no direct significant CCS scope effects on WTP, the interaction between CCS scope and certain spatial variables reveals significant insights on how local environmental and energy contexts influence WTP sensitivity to scope.

Specifically, the results indicate a positive relationship between protected forest cover and WTP for CCS with 10MT CO2 reduction. Respondents living in areas with a high density of protected forest cover (over 15%) are willing to pay significantly more for CCS in the 10MT scenario (530 DKK) compared to the 5MT scenario (440 DKK). This suggests that local natural amenities can shape scope sensitivity, possibly due to perceived environmental benefits or a preference for larger-scale mitigation efforts. Proximity to Denmark's West Coast also emerged as a key factor, with respondents closer to the coast showing higher WTP for the 10MT CO2 CCS project, compared to the 5MT scenario. These patterns indicate that geographical location and local environmental conditions significantly influence peoples' sensitivity to scope when evaluating new climate mitigation energy technologies.

Regarding spatial features of the existing energy landscape, the results indicate that exposure to complementary energy systems, i.e., underground gas storage facilities and emitting energy plants, has no significant influence on WTP scope sensitivity. In contrast, we find significant scope effects, induced by proximity to existing renewable energy systems (CCS substitutes). Specifially, the results show that having at least one larger-scale solar farm within a 2.5km travel radius results in significantly lower WTP for the 5MT CCS scenario (333 DKK) compared to the 10MT CCS project (400 DKK). These findings underscore that while CCS project scope itself seems to have no direct impact on WTP, its interaction with distinct spatial factors significantly affects preferences and WTP for CCS deployment.

Conclusions

This is the first valuation study investigating spatially induced scope effects on WTP for novel low-carbon energy technologies. Based on stated preference data and respondent-specific spatial information, we find that distinct spatial characteristics, such as protected forest cover, coastal proximity, and exposure to renewable energy infrastructure, significantly influence peoples' sensitivity to scope when evaluating the implementation of CCS with varying emission reduction potentials. This highlights the importance of considering local environmental contexts and infrastructural features when assessing public preferences of low-carbon energy technologies.

The study's findings provide new empirical evidence on the interlinkage between spatial effects and WTP scope sensitivity, relevant for the planning and implementation of new energy initiatives. Project planners and decision-makers can be adviced to carefully consider geographic and environmental features when selecting CCS sites, while also taking into account the technologies contribution to emission reduction goals. Designing targeted and site-specific communication strategies can promote community acceptance for new energy infrastructure development, and hence facilitate a socially just green energy transition.

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