Research & Methods
ISSN 1234-9224, e-ISSN 2544-0799
Vol. 32 (1, 2023)
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https://doi.org/10.18061/ask.v32i1.0005

Stability and Determinants of Social Acceptance of Innovative Sustainable Technologies. Evidence from a Two-Wave Panel Study.

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Abstract This study investigates the role of attitudinal factors in shaping the acceptance of emerging sustainable technology. Using panel data from two waves of surveys conducted in two districts of the city of Cologne, Germany (N = 204), this paper discusses the impact of environmental, prosocial, and technology attitudes, as well as beliefs about the costs and benefits of the technology. The study is part of an interdisciplinary research project, VertiKKA, funded by the Federal Ministry of Education and Research (BMBF).

Autoregressive and cross-lagged structural equation models (SEM) are applied to examine the stability of attitudinal factors and their impact on the acceptance of the sustainable technology. The results of the study suggest that while most of the attitudinal factors analyzed show stable autoregressive effects, the acceptance of sustainable technology is more volatile. We also find that general attitudes have a significant impact on beliefs about benefits, while only general environmental attitudes have an effect on beliefs about costs. Both beliefs function as total mediators between general and specific attitudes, with benefits having a greater influence on acceptance than cost aspects.

Overall, the study highlights the importance of considering attitudinal factors in understanding the acceptance of sustainable technologies. The results provide insights that could inform the design and promotion of sustainable technologies, as well as help policymakers and practitioners to develop effective strategies to increase their adoption.

Keywords: structural equation modeling, attitudes, technology acceptance, environmental technologies

INTRODUCTION

According to estimations of the United Nations, more than two-thirds of the world's population will live in cities by the year 2050. Sustainable city development, as a part of the Sustainable Development Goals, is already a big challenge today and will rise in its importance when it comes to adapting to the consequences of climate change (United Nations, 2022).

Urban green is a crucial part of this development as it improves the urban micro-climate and reduces air pollution, increases biodiversity, protects soil and groundwater, and helps with cooling, noise, and rainwater drainage (Aronson et al., 2014; Knight et al., 2021; VertiKKA, 2022; Zhang et al., 2012). Furthermore, it elevates the attractiveness of locations and increases the well-being of the residents (Bertram & Rehdanz, 2015). Another consequence of increasing urban density is the limitation for green urban space. Facade and roof greening are promising possibilities to change the proportion of greenery even with little space available. Additionally, sustainable energy technologies and water recycling/irrigation systems can complement each other effectively and create synergies (VertiKKA, 2022). Although various sustainable (energy) technologies are already available and further advances are constantly made, the implementation on a large scale requires public participation and acceptance to be successful (Wüstenhagen et al., 2007).

The acceptance of specific emerging technologies has been shown to be dependent on the type of technology and scale of implementation (Gupta et al., 2012; Heiskanen et al., 2008). However, sustainable technology acceptance relies not only on the technology characteristics or functionality, but even more, these factors sometimes play a rather minor role. Other influential predictors for technology acceptance are perceived benefits, risks, and costs (Balcombe et al., 2014; Bronfman et al. 2012; Gupta et al., 2012; Heiskanen et al., 2008; Kosorić et al., 2019; Visschers & Siegrist, 2014). According to Spandagos, Tovar Reaños and Lynch (2022), the social support of new technologies is dependent on both demographic factors, as well as attitudinal factors in the context of politics, environment and technology in general.

The present study aims to understand and explain the emergence of acceptance of new environmental technologies and the role of general attitudinal factors (regarding the environment, technology, and prosocial behavior) as well as more behavioral specific factors (perceived cost and benefits). Since most of empirical evidence regarding sustainable technology acceptance derives from cross-sectional studies (Kosorić et al., 2019; Tabi & Wüstenhagen, 2017; Visschers & Siegrist, 2014), little is known about the stability of attitudes and beliefs over time, especially when considering new innovative technologies. For this purpose, a two-wave panel study was conducted in order to contribute to the existing matter literature.

This research is part of an interdisciplinary research project called VertiKKA[1] (in German **Verti**kale-**K**lima-**K**lär-**A**nlage), that is a vertical air-conditioning and water recycling system, funded by the Federal Ministry of Education and Research (BMBF).

THEORETICAL BACKGROUND

According to the Technology Acceptance Model (TAM), technology acceptance is understood as a function of beliefs, which are shaped by individual factors, system characteristics, social influences and external conditions (Davis, 1989; Venkatesh et al., 2003; Venkatesh & Bala, 2008). In TAM, these beliefs concern the perceived "ease of use" and "usefulness" of a technology, which in turn are seen as the main predictors of both; use intention and actual usage behavior.

Furthermore, technology acceptance can be explained through the lens of attitude-behavior research (for instance Theory of Planned Behavior (TPB) of Ajzen, 1985; Ajzen & Madden, 1986; Fishbein & Ajzen, 2010). Here, a causal chain is assumed, that starts with generalized and stable judgments, such as social values and attitudes, leading to more specific perceptions and attitudes, which finally explain specific individual intentions and behavior (e.g., Best & Mayerl, 2013; Eagly & Chaiken, 1998; Mayerl & Best, 2019; Rokeach, 1968; Stern & Dietz, 1994).

We intend to combine both perspectives in order to provide a more nuanced and multifaceted understanding of the phenomenon of technology acceptance. The proposed analytical framework seeks to explain specific attitudes towards emerging environmentally sustainable technology by incorporating generalized attitudes as major predictors of attitude. Moreover, we posit that general attitudes towards technology, in particular, might constitute a crucial factor in predicting attitudes towards specific emerging technologies.

Instead of explaining behavioral intention directly as TAM does, we propose to take a step back in the causal chain of attitudes-behavior relation and explain specific attitudes towards the emerging technology. We model specific beliefs such as "perceived usefulness" and "perceived ease of use" as mediators between general and specific attitudes. While these beliefs may be relevant to some technologies, simultaneously they may not be exhaustive or even accurate for all technologies. Based on the current state of research, we will identify other potential beliefs and general attitudes that may play a role in explaining attitudes towards the specific environmentally sustainable technology we investigate. By extending the predictive power of TAM through the incorporation of generalized attitudes, the aim is to provide a more comprehensive understanding of the attitudinal factors that influence technology acceptance and usage behavior.

STATE OF RESEARCH

As the quantity of technological innovations grows with technological progress, a variety of these innovations have been studied across many countries in recent decades (for an overview of sustainable energy innovation see Spandagos et al., 2022). For instance, there are studies examining the acceptance of home micro-generation of renewable energies like solar, heat pumps, biomass or domestic hydrogen (Balcombe et al., 2014; Gordon, Balta-Ozkan & Nabavi, 2022; Heiskanen & Matschoss, 2017; Peñaloza et al., 2022; Yuan, Zuo and Ma 2011), community renewable energies, micro-grids and energy storage (Müller & Welpe, 2018; Tabi & Wüstenhagen, 2017; Warneryd et al., 2020) and even a study (Kosorić et al., 2019) which investigates attitudes towards a combination of different multi-functional innovations as discussed within this paper too. Kosorić et al., (2019) investigate the social acceptance of a productive façade concept integrating photovoltaic and farming systems by the residents of high-rise public housing blocks in Singapore.

Among all identified predictors, perceived risks and perceived benefits (and recently also perceived costs) are some of the most analyzed ones (Gordon et al., 2022; Gupta et al., 2012). Perceived risks, which refer to the perception regarding the uncertainty and potential negative effects of a specific technology (Gordon et al., 2022), seem to strongly reduce public support for the building of large-scale infrastructure projects such as nuclear power plants and fossil fuels. Nevertheless, they are either less strongly or not related to the acceptance of unconventional renewable energy resources (Bronfman et al., 2012).

By exploring differences and similarities in the acceptance of five different energy technologies (hydro, solar, nuclear, gas-fired and wind power), Visschers & Siegrist (2014) find that, among all variables, perceived benefits are most strongly related to the acceptance of each of the five technologies, even if there are minor differences between the technologies (stronger impact on the acceptance of gas power than on the acceptance of hydro, nuclear and wind power). Similarly, Bronfman et al. (2012) and Heiskanen et al. (2008) identify perceived benefits as a "key predictive factor" when considering social acceptance of new sources of electricity generation or low-carbon heating technologies. Moreover, Bronfman et al. (2012) construct a "causal-trust acceptability" model and prove that the relationship between trust and acceptability is both direct and indirect, mediated by perceived risk and perceived benefits.

Perceived costs are much less studied (but see Gupta et al., 2012). Kosorić et al. (2019) find that the most pressing concern for the acceptance of productive façades (integration of photovoltaic and vertical farming) among the residents of high-rise public housing blocks is perceived costs. Similarly, Balcombe et al. (2014) state that financial factors are the most relevant barriers to a household's decision to adopt of microgeneration technologies such as solar photovoltaics, solar thermal, wind and heat pumps.

Among general attitudes, environmental concern, and attitudes towards climate change, are found to be influential predictors (Decker et al., 2009; Spandagos et al., 2022; Tabi & Wüstenhagen, 2017; Urban & Ščasný, 2012; Visschers & Siegrist, 2014). People with higher environmental concern and those who take climate change seriously show on average more likely positive attitudes towards technologies or adopt such technologies.

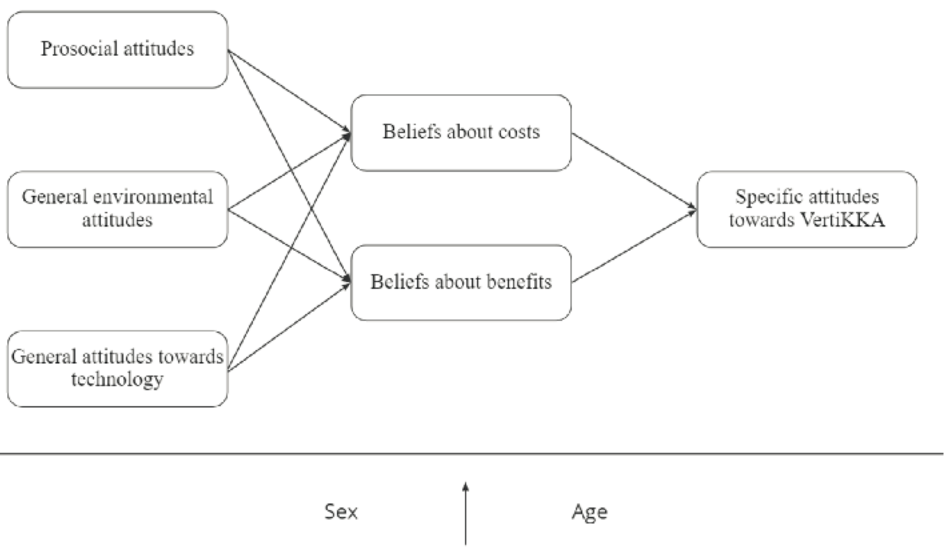
PROPOSED MODEL

In the present study, we aim to extend previous research in two ways: First, we are interested in explaining the acceptance of an environmentally sustainable technology (VertiKKA) by attitudinal and cost-benefit determinants. Second, we are interested in the question of how stable attitudes and beliefs are over time.

We assume that perceptions of benefits as well as perceptions of costs will be significantly related to the specific attitudes towards VertiKKA. As perceptions of risks rather influence (lack of) support for large-scale "risk technologies" as nuclear power plants than for unconventional renewable energy innovations, where risks do not seem particularly evident, we do not include these in our model (Bronfman et al., 2012). Kosorić et al. (2019) identified perceived costs as the largest barrier to acceptance of their integrated façade greening technology. Given this technology is found to be the closest to the subject of this study, we include the perception of costs in our model.

The benefits of VertiKKA are not only economic but mainly ecological, which is why the technology is to be classified in the category of "green" or "sustainable" technologies. Moreover, existing research shows that environmental attitudes might be an influential predictor. Therefore, environmental attitudes are one core of the theoretical modelling. Next to environmental attitudes, and general attitudes towards technologies, we further include general prosocial attitudes. We assume that prosocial attitudes have an effect either because VertiKKA is a technological innovation that not only has self-serving benefits (e.g. cooling of indoor spaces), but also collective benefits (e.g. relief of sewers and sewage treatment plants by recycling grey water). Additionally, the whole impact (reduction of heat islands, improvement of air quality and fine dust pollution, reduction of noise pollution) only unfolds when several of these modules are used in a neighborhood. Supporting the technology benefits the neighborhood, just as one benefits when other residents support the installation of the technology on their residential buildings. As already outlined, according to the tradition of hierarchical attitude theory we hypothesize that these generalized attitudes (environmental attitudes, prosocial attitudes, attitudes towards technology) lead to more specific perceptions (beliefs about benefits and costs), which in turn finally explain specific attitudes towards VertiKKA. Beliefs about costs and benefits are therefore mediating variables (see Figure 1).

Figure 1. Theoretical model.



As there might be individual differences in the perception of the technology (as also stated in TAM), sex and age are included as control variables in the model (see also Heiskanen & Matschoss, 2017).

DATA AND METHODS

Sample

We draw a random sample at individual-level by address lists of the Residents' registration office in Cologne from two districts (Ehrenfeld, Nippes) of the city of Cologne in Germany. The city of Cologne was chosen as VertiKKA is planned to be implemented in the district Ehrenfeld. The district Ehrenfeld is one of the districts in Cologne most affected by heavy rainfall events and heat. Nippes was chosen as the control district and is, as well as Ehrenfeld, strongly affected by intense rainfall events and heat and has similar socio-demographic data in terms of the unemployment rate, average age, and proportion of people with migration background.

The first data collection took place from 15th March to May 2020. Gross samples were 3000 residents from Ehrenfeld and 600 residents from Nippes. A total of 517 respondents, thereof 413 from Ehrenfeld and 97 from Nippes completed the questionnaire, which results in an overall response rate of 14.4%. The survey was conducted as mixed mode survey with 1200 postal questionnaires (305 returned, 25.4%) and 2400 push-to-web online surveys (212 returned, 8.8%).

All respondents who stated they were willing to take part in a follow-up survey (N = 400) were sent the second (push-to-web online) questionnaire.[2] Since at this time sketches and photos of a prototype of VertiKKA were available, a survey experiment was included (see Online Appendix *Figure B*). Randomly 75% of the respondents were shown a visual information treatment of VertiKKA placed before questions about specific attitudes to assess if a more specific idea of how VertiKKA looks like could influence the assessment towards the technology. The second data collection took place from 22nd November 2021 to January 2022. The final sample consists of 204 respondents (response rate 50.8%). The mean age is around 45 years and 55% of the sample are women.

Measures

All items for this study as well as descriptive statistics are presented in Table 1. General attitudes and specific attitudes towards VertiKKA were answered on a 5-point response scale (from 1 = does not apply at all/not important at all to 5 = applies fully/very important). Beliefs about the costs and benefits of VertiKKA were answered on a 7-point response scale (from 1 = not important at all to 7 = very important).

Prosocial attitudes are measured by two items asking for the personal priority of social support and if everyone should spend time for the good of their city/ community. *General environmental attitudes* are measured by two items asking

Table 1. Measures and descriptives.

Construct	Item (translation from German)	t1 Mean (SD)	t2 Mean (SD)
Attitudes towards VertiKKA	I find the use of technical innovation in the field of façade greening very useful. (useful)	4.04 (0.92)	4.42 (0.8)
	I would like to live in a house with façade greening. (like2live)	4.09 (1)	4.25 (0.93)
	I think that a house with façade greening is better than a house without façade greening. (better)	3.83 (1.05)	4.02 (1.07)
	How much would it be worth to you financially to live in a building with façade greening? (value)	3.45 (0.68)	3.64 (0.7)
Beliefs about benefits	Importance of ecologically sustainable housing and assessed expected probability of occurrence by VertiKKA. (sus_liv_pu)	17.88 (5.24)	19.54 (4.93)
	Importance of recycling of wastewater and probability of assessed expected occurrence by VertiKKA. (recovery_pu)	13.31 (5.86)	15.37 (5.49)
	Importance of living in a green environment and assessed expected probability of occurrence by VertiKKA. (gr_liv_pu)	16.98 (5.75)	17.89 (5.75)
	Importance of air quality of living environment and assessed expected probability of occurrence by VertiKKA. (air_pu)	17.11 (5.23)	17.41 (5.25)
Beliefs about costs	Importance of lowest possible housing costs and assessed expected probability of occurrence by VertiKKA. (low_cost_pu)	10.33 (5.09)	11.39 (5.58)
	Importance of avoidance of renovations, refurbishments and repairs to residential building and assessed expected probability occurrence by VertiKKA. (avoid_cost_pu)	8.04 (4.98)	8.69 (4.64)
General environ-mental attitudes	In our industrialized world there is a limit for growth that has already been exceeded or will soon be exceeded. (lim_liv)	4 (0.98)	4.05 (0.98)
	I would give up part of my income if I could be sure that the money would be used for environmental protection. (give_inc)	3.42 (1.23)	3.43 (1.21)
General attitudes towards technology	I quickly enjoy new technical developments. (like_innov)	3.23 (1.13)	-
Prosocial attitudes	If a person need support, then that has the highest priority for me. (sup_prior)	3.71 (0.85)	-
	Everyone should spend something of their time for the good of their city or community. (time_com)	3.76 (0.84)	-
Demographics	Sex (1= male)	0.45	-
	Age	45.41 (13.27)	-

Notes. N = 204.

respondents if there is a limit of growth in the industrialized world that has already been exceeded or soon be exceeded and if respondents would give up part of their income for environmental protection. *General attitudes towards technologies* are operationalized through a single indicator, asking respondents if they quickly enjoy new technical developments.

Beliefs are operationalized as subjective expected utility[3] of system characteristics: *perceived benefit beliefs* concern sustainable housing, recycling of wastewater, living in a green environment, and air quality. *Perceived cost beliefs* concern low housing costs and the avoidance of renovations, refurbishments, and repairs to the residential building.

After introducing the concept of VertiKKA in a small text, the *specific attitudes towards VertiKKA* are measured by asking for the usefulness of technical innovations in the field of façade greening, if the respondent would like to live in a house with façade greening, if they think that such house is better than ones without and how much it would be financially worth for them to live in a house with façade greening. On a descriptive level, overall attitude towards VertiKKA is quite high with an average agreement to the items of almost 4 on a 5-point-response scale (see Table 1).

Control variables: Due to the implementation of a visual information treatment in 75% of the surveys, we include a dummy control variable indicating this experimental stimulus (visual information shown 0/1). Demographic control variables for every latent variable are sex and age.[4]

Analytical strategy

We estimate the relationship between general attitudes towards the environment, technology, and social cohesion and beliefs about the costs and benefits of the environmental technology as well as specific attitudes towards VertiKKA using structural equation modelling (SEM). This approach allows us to estimate relationships between latent constructs, taking measurement errors on the level of indicator variables into account (see Kline, 2016). Missing values are treated with full information likelihood estimation (FIML) (Kline, 2016; Urban & Mayerl, 2014). All analyses are conducted with R version 4.1.3 and lavaan package version 0.6-11 (Rosseel, 2012).

First, we run confirmatory factor analysis (CFA) to analyze the measurement model of all latent constructs. We then estimate the hypothesized model to assess the hierarchical structure as well as the stability of the attitudes. Stepwise, we adjust this model to dig into lagged and contemporary effects between the model components.

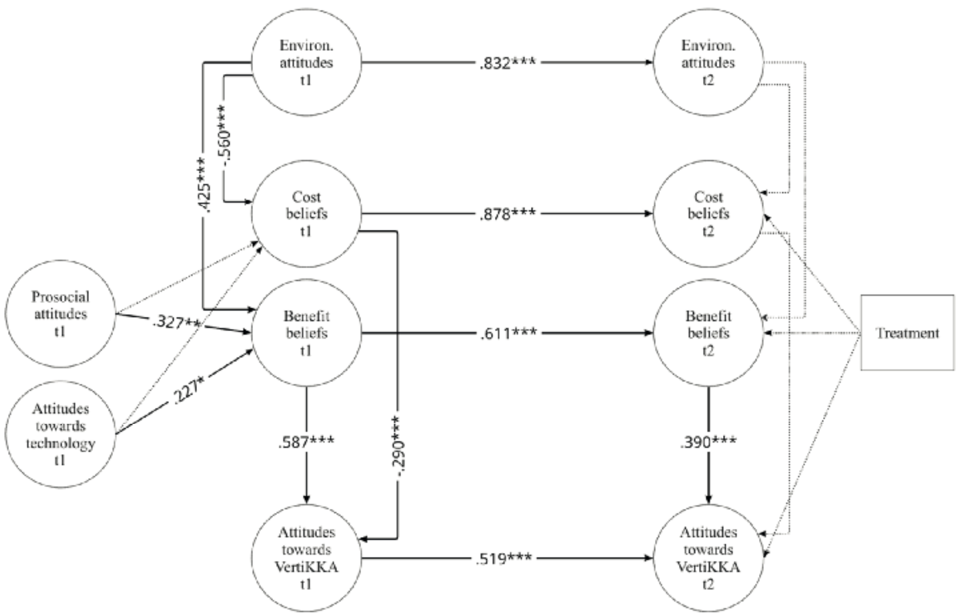
RESULTS

The CFA shows satisfactory construct validity of all latent constructs (see Online Appendix *Table C*) and the model shows acceptable overall fit in line with the thresholds formulated by the literature (Kline, 2016; Urban & Mayerl, 2014): $\chi^2 = 388.280$, df = 351, p = .000; CFI = .942, RMSEA = .049 95% CI [0.038, 0.059], SRMR = .053. All factor loadings are statistically significant ($p < .01$) with standardized loadings above 0.5 with no exception, i.e. convergent validity can be assumed. The model fit is acceptable without the need for specifying further cross-loadings, meaning discriminant validity can be assumed to be given as well. In order to improve the model fit, three measurement error covariances per time point are specified for reasonable substantive reasons.[5] Since these error correlations are low (Pearson's *r* between .12 and .29), this does not pose a problem for convergent or discriminant validity. As we analyze panel data, autocorrelations of measurement errors within the same construct at different points in time are specified and measurement invariance is established (for detailed results and Chi²-test see Online Appendix *Table D*). The latter ensures that observed changes over time actually represent the growth of a construct and not just that the construct itself has changed in nature (see for example Ferrer, Balluerka & Widaman, 2008; Mayerl & Andersen, 2019; Urban & Mayerl, 2014). Metric invariance (also known as "weak" factorial invariance) is seen as necessary and adequate for looking at relations between constructs across groups or points in time (Kline, 2016).

Subsequently, the hypothesized lagged-effects model is empirically tested (see Online Appendix *Figure E*), which includes contemporary effects between general attitudes, beliefs, and specific attitudes at the first point of time, since the specific attitude towards VertiKKA is assumed to be shaped here for the first time. Also, this model contains lagged effects as well as autoregressive paths in order to examine lagged causal effects of beliefs on the specific attitude over time (beliefs t1 → specific attitude t2), while controlling for prior attitudes in time and assessing the stability of beliefs and attitudes over time (e.g. specific attitude t1 → specific attitude t2). The model fit is acceptable with $\chi^2 = 469.930$, df = 343, p = .000; CFI = .943, RMSEA = .043 95% CI [0.033, 0.052], SRMR = .055.

As an alternative model, a model with contemporary effects (instead of lagged effects) between beliefs and attitudes is tested (see *Figure 2*). This model shows also an acceptable fit ($\chi^2 = 477.931$, df = 347, p = .000; CFI = .942, RMSEA = .043 95% CI [0.033, 0.052], SRMR = .055). Interestingly, the results of the lagged-effects model are substantively identical to the model with contemporary effects, that is: significant effects of benefit beliefs on attitudes. Comparing the strength of the effects of benefit beliefs on attitudes in both models (beliefs t1 → specific attitude t2 vs. beliefs t2 → specific attitude t2), we observe stronger effects in the contemporary model compared to the lagged model (see more details on these model comparisons in the Online Appendix). We interpret this as a sign that attitudes towards a new technology are generated rather on the spot, based on recent cognitions, in contrast to lagged effects which unfold over a longer time. Therefore, we focus on the contemporary model (*Figure 2*) for the rest of this paper, but it is worth emphasizing that both models share the same substantial results.

Figure 2. Empirical model of the hierarchical attitudinal structure of attitudes towards VertiKKA (contemporary and autoregressive effects).



Notes.
standardized effects: *** p < .001, ** p < .01, * p < .05, n.s. p > .05; dotted paths are n.s.; control variables: sex and age; Fit: χ^2 = 477.931, df = 347, p = .000; CFI = .942, RMSEA = .043 95% CI [.033, .052], SRMR = .055; FIML estimator; N = 204; indicators and covariances are not shown.

As expected, at time t1, environmental, prosocial and technology attitudes have significant positive effects on the beliefs about benefits, while environmental attitudes have the strongest effect and general attitudes towards technologies the weakest. With regard to the beliefs about costs, only environmental attitudes have a significant effect, that is unsurprisingly negative. This means, the more someone is environmentally aware, the less this person cares about the costs and the more about the benefits of VertiKKA. As hypothesized, both beliefs influence the specific attitudes about VertiKKA. The beliefs about costs have a highly significant negative effect and the beliefs about benefits have a highly significant positive effect. By comparing two models, one with a total mediation pattern and one with a partial mediation pattern, it is found that the effects of the general attitudes on the specific attitudes are, in line with our theoretical model, fully mediated by both beliefs. A Chi²-test ($\Delta\chi^2 = .244$, $\Delta df = 3$, $p > .05$) shows that the model without direct effects from general attitudes to specific attitudes is not significant worse than the model with those effects.

All autoregressive paths are highly significant and show standardized coefficients from 0.52 in the case of the specific attitudes to 0.88 in the case of beliefs about the costs. Autoregressive effects can be interpreted as stability coefficients with higher estimates typically indicating stronger stability (Urban, 2004). Thus, most stable are environmental attitudes as well as beliefs about costs, while the specific attitudes are less stable.

In contrast to t1, in t2 beliefs about costs and general environmental attitudes do not have a significant effect on the specific attitudes. This implies that besides already habituated acceptance, over time attitudes towards VertiKKA are influenced only by beliefs towards *benefits* of the technology. Further, the experimental treatment variable we included in the model does not show any effects on beliefs or attitudes. Hence, it might be assumed that the materials provided did not lead to a different understanding or idea of VertiKKA among the respondents.

DISCUSSION

One of the main tasks of the future urbanism is the sustainable development of cities and communities. Besides the inequality, urban energy consumption and pollution are among the most critical challenges facing cities worldwide (United Nations 2020). Façade greening modules and sustainable energy technologies could make a crucial contribution to this development if they are accepted and used by people. This study extends previous research by examining the emergence of acceptance towards an integrative sustainable technology that combines façade greening, photovoltaics, and greywater treatment (VertiKKA). We analyzed the relationship between general attitudes towards the environment, technology, and social cohesion; beliefs about the costs and benefits of the technology and attitudes towards the technology itself in a sample consisting of 204 adults from Cologne, Germany, who are potential future users.

In line with previous studies (Gordon et al., 2022; Jung et al., 2016; Spence et al., 2010; Tampakis et al., 2013; Visschers & Siegrist, 2014), which find that renewable energy resources such as solar, wind, and hydro-power receive the highest levels of acceptance of all types of energy resources, VertiKKA receives predominantly positive ratings. The study by Kosorić et al. (2019), which examines similar integrative modules, also shows that 80.2% have an overall positive attitude towards these.

Structural equation modelling showed the expected hierarchical attitudinal structure with general attitudes guiding beliefs, which in turn determine specific attitudes. In this sense, beliefs act as a total mediator variable for the relationship between general attitudes and specific attitudes. While beliefs towards *benefits* are determined by all three general attitudes, beliefs towards costs of VertiKKA are only influenced by environmental attitudes. Both beliefs, in turn, influence specific attitudes. These results are consistent with the well-known (Best & Mayerl, 2013; Eagly & Chaiken, 1998; Stern & Dietz, 1994) hierarchical attitude structure, where specific attitude are deduced from more general beliefs and, likewise, these beliefs are deduced by even more general attitudes.

Interestingly, these findings can confirm the observation that perceived benefits are stronger predictors of specific attitudes towards sustainable technologies than perceived costs or general attitudes (Bronfman et al., 2012; Frewer et al., 1998; Gordon et al., 2022; Visschers & Siegrist, 2014). As we collected data at two points in time, we are even able to extend this finding: perceived benefits are not only the strongest predictor at time 1, but the only predictor, besides the already habituated attitude, of specific attitudes at time 2. Although in the period of attitude development the perceived costs, in terms of repairs and housing costs, are also significant for acceptance, in later phases this cost aspect no longer matters, i.e. residents become accustomed to any costs that may arise in the case of visible benefits. This means, it is primarily the perceived benefits, which by itself are predominately influenced by environmental awareness, that determine the acceptance of VertiKKA. We also found that beliefs about costs do not have substantial lagged effects, and that the lagged effects of benefit beliefs are remarkably weaker compared to its contemporary effects (and even disappear in a simultaneous model, see Online Appendix). This may be because the technology is so new that rather newly formed benefit beliefs predict attitudes than beliefs formed seven months ago.

The stability coefficient of the specific attitudes is the least stable of all, however, given that it is an attitude that is presumably only formed at the time of the survey, it is remarkably stable. This indicates that once aspects from the fields of technology, environment and social cohesion have been associated with VertiKKA, the individual differences in acceptance of VertiKKA remain stable. Further, the varying stability of the constructs in the way that general environmental attitudes are more stable than specific attitudes remains consistent with the state of the research. It is well-known that more general attitudes and basic values are the "more stable and less vulnerable to the impact of current events" (Schwartz et al., 2010), whereas specific attitudes are more volatile.

Strengths and limitations

The present study analyzed the attitudes towards a technology that combines components of façade greening, photovoltaics with innovative wastewater management. To our knowledge, the present study is the first to use longitudinal data in this branch of technology acceptance research, allowing us to assess the stability of (potentially newly formed) attitudes and beliefs. Furthermore, we examined the hierarchical relationship of several important general attitudes in the field of technology, environment and social cohesion with beliefs and specific attitudes, so that we could make claims about how attitudes towards new technologies come into existence by its potential future users. We tested our theoretical model with SEM, which allowed for latent variable analyses to control for measurement error, while testing complex relations between variables.

However, the research design has also some limitations: the sample is biased due to the restriction of only two districts in the German city of Cologne, a relatively minor number of cases and an overrepresentation of people with higher educational degrees. In addition, the questionnaire was only implemented in German, which excludes non-German speakers. Since the participation in the second wave was based on a query in the first survey, it is likely that particularly interested people participated in the panel study and therefore the acceptance of VertiKKA is overestimated. Though it is one strength of the current study that panel data are used, two waves are still not sufficient for the application of fixed effects models, which would allow controlling for unobserved heterogeneity (see Andersen & Mayerl, 2022).

Nevertheless, another limitation of our study is that the VertiKKA technology does not exist yet, all assessments are based solely on imagination and not on actual experience with the technology.

Conclusion

The present research complements previous work by pointing the emergence of the acceptance towards an innovative sustainable technology and examining this acceptance over time. It is primarily utility beliefs that condition the acceptance of VertiKKA. These utility beliefs are predominantly immaterial in nature, i.e. they refer to abstract and lifestyle-oriented values rather than reflections on technical, material or rational benefits. This immaterial expected benefit is predominantly determined by environmental awareness, subordinate also by general technology acceptance and prosocial attitudes. Once aspects from these fields have come into association with VertiKKA, the individual differences in acceptance of VertiKKA remain stable (according to the rather strong autoregressive effects). That means, campaigns may neglect other aspects (prosocial, environmental, technical) over a longer period of time while maintaining the visibility of (immaterial) benefit aspects. Further, while in the initial period of attitude development the perceived expected costs, in terms of repair work and rental prices, are also significant for acceptance, this cost aspect no longer plays a role, i.e. recipients become accustomed to any costs incurred in the case of visible benefits. Accordingly, the implementation of innovative technologies should always be carried out by highlighting their benefits.

NOTES

1 VertiKKA aims to combine components of façade greening and photovoltaics with innovative wastewater management and to make use of synergy effects (photovoltaic modules protect the plants against extreme weather conditions, used water is permanently available as irrigation water and higher photovoltaic electricity yields due to the cooling effects of the plants).

2 Due to the auto-selection into the second wave, which introduces the problem of narrowing the sample, additional robustness checks were carried out with the total sample of wave 1 (see Online Appendix *Figure A*). The estimations did not differ substantially in their strength and direction, thus providing confidence that the analysis of the limited sample is reasonable.

3 In line with SEU theory (e.g. Coleman, 1990) and Theory of Planned Behavior (e.g. Ajzen 1985), we asked for the *evaluation*/*importance* as well as the assessed *expected probability* of occurrence of the mentioned issues. The answers of both scales were multiplicated, such that respondents who score high think that a feature is important *and* expect that it will likely occur.

4 We also estimated our models with the district of residence variable as a control variable. However, since there are no significant effects and we want to keep our models as parsimonious as possible due to the small number of cases, it is not included in the final models.

5 Three measurement error covariances within each time point were specified: between item like2live and better (attitude object: house with façade greening), between item value and like2live (attitude object: house with façade greening), and between item value and give_inc (monetary value).

FUNDING

This work was supported by Federal Ministry of Education and Research of Germany (BMBF) under grant number 033W108A-K. We thank the BMBF for supporting this research. The official website of the project can be found here: https://vertikka.de**.**

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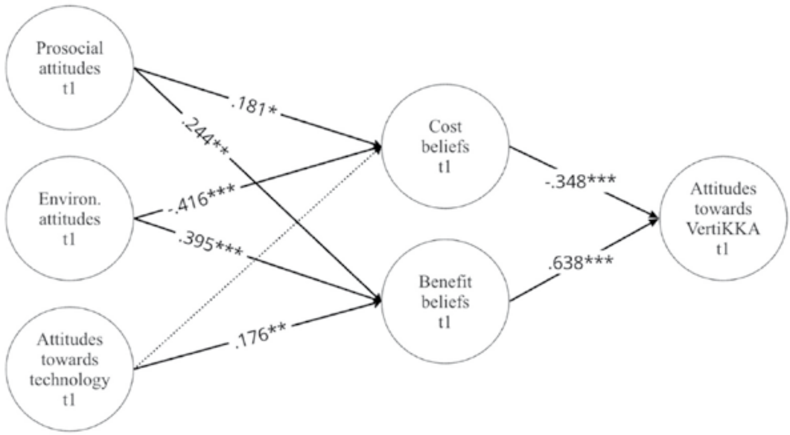
ONLINE APPENDIX

Figure A. Empirical model of the hierarchical attitudinal structure of attitudes towards VertiKKA (total sample of wave 1).



Notes.
standardized effects: *** p < .001, ** p < .01, * p < .05, n.s. p > .05; dotted paths are n.s.; control variables: sex and age; Fit: χ^2 = 222.227, df = 96, p = .000; CFI = .943, RMSEA = .051 95% CI [.043, .060], SRMR = .044; FIML estimator; N = 498; indicators and covariances are not shown.

Figure B. Visual information treatment of VertiKKA.

Table C. Results of confirmatory factor analysis (adjusted measurement model with configurative invariance).

		t1			t2		
Factor	**Item**	**b**	**se**	**b***	**b**	**se**	**b***
factor loadings							
spec_att	useful	1.000	0.000	0.626	1.000	0.000	0.675
spec_att	like2live	1.529	0.184	0.897	1.585	0.170	0.916
spec_att	better	1.405	0.174	0.784	1.591	0.179	0.802
spec_att	value	0.775	0.104	0.663	0.833	0.108	0.637
beliefs_nutz	air_pu	1.000	0.000	0.640	1.000	0.000	0.715
beliefs_nutz	recovery_pu	0.986	0.145	0.567	0.989	0.123	0.629
beliefs_nutz	gr_liv_pu	1.150	0.141	0.665	1.218	0.120	0.748
beliefs_nutz	sus_liv_pu	1.205	0.145	0.782	1.152	0.123	0.772
beliefs_cost	low_cost_pu	1.000	0.000	0.725	1.000	0.000	0.562
beliefs_cost	cost_avoid_pu	0.854	0.172	0.633	0.908	0.243	0.613
gen_env	lim_liv	1.000	0.000	0.688	1.000	0.000	0.758
gen_env	give_inc	1.166	0.234	0.640	0.947	0.210	0.585
tech_gen	like_innov	1.000	0.000	0.836	-	-	-
prosocial	sup_prior	1.000	0.000	0.680	-	-	-
prosocial	time_com	0.821	0.257	0.565	-	-	-

Notes.
Fit: χ^2 = 388.280, df = 351, p = .000; CFI = .942, RMSEA = .049 95% CI [.038, .059], SRMR = .053;
FIML estimator; N = 204; all coefficients are significant at 1-percent-level.

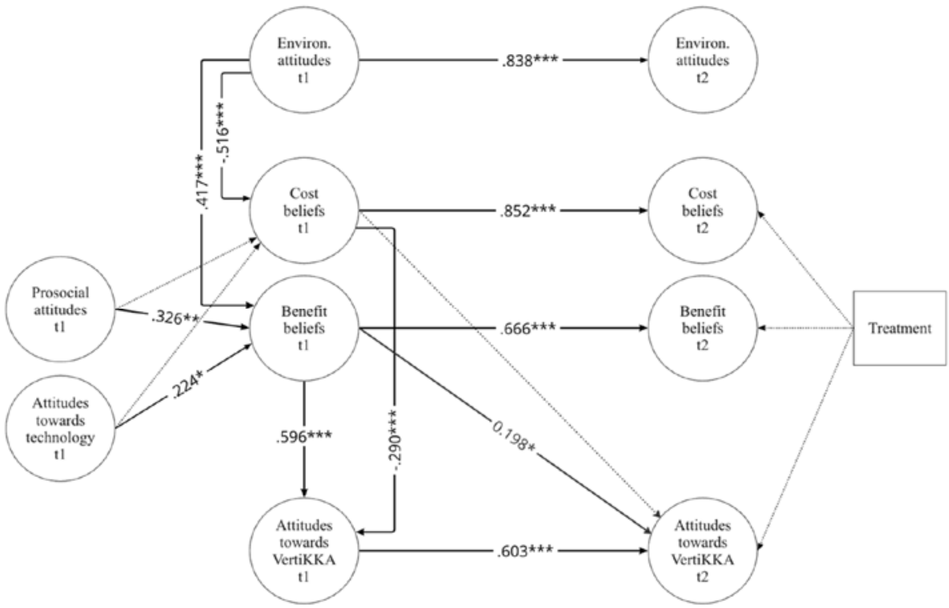
Table D. Comparison of the models with configurative invariance and metric invariance.

Model	χ^2	p-value	*df*	CFI	RMSEA	$CI_{90\%}$ RMSEA	SRMR
Configurative	388.280	.000	351	.942	.049	[.038, .059]	.053
Metric	391.395	.000	269	.945	.047	[.037, .058]	.054

Notes.
FIML estimator; N = 204, all coefficients are significant a 1 percent level.

Metric measurement invariance is not associated with a significant chi-square increase ($\Delta\chi^2 = 3.116$, $\Delta df = 8$, $p > .05$).

Figure E. Hypothesized model of the hierarchical attitudinal structure of attitudes towards VertiKKA (contemporary (t1), lagged, and autoregressive effects).



Notes.
standardized effects: *** p < .001, ** p < .01, * p < .05, n.s. p > .05; dotted paths are n.s.; control variables: sex and age; Fit: χ^2 = 469.930, df = 343, p = .000; CFI = .943, RMSEA = .043 95% CI [.033, .052], SRMR = .055; FIML estimator; N = 204; indicators and covariances are not shown.

Notes on model comparisons

While the contemporary effects of the **hypothesized model** (*Figure D*) at time t1 are mainly significant and strong, the lagged effects are either not statistically significant (p > .05) (cost beliefs t1 → specific attitude t2) or extremely close to the 5% significance level (p = .49) (benefit beliefs t1 → specific attitude t2).

We tested another model (not shown), in which we added **contemporary effects**, simultaneously to time point t1, also at **time point t2** (e.g. beliefs t2 → specific attitudes t2). Thus, the lagged effects (beliefs t1 → specific attitude t2) become completely insignificant, while one of the contemporary effects becomes highly significant (benefit beliefs t2 → specific attitudes t2).

For the sake of completeness, we also tested for **cross-lagged effects** (not shown), both in the model without contemporary effects at time point t2 (hypothesized model) and in the model with contemporary effects at time point t2. In terms of a Chi²-test of the different models, both models with cross-lagged effects are not significantly better than those without cross-lagged effects ($\Delta\chi^2$ > 5, p > .05). Moreover, cross-lagged paths do not contribute substantially to the explanation of the acceptance of the technology (but to the explanation of beliefs in t2).