



Original research article

Beyond the 'skills gap': German installation enterprises need organisational restructuring to implement low-carbon transitions

Simon Wehden^{a,b,*}, Kathryn B. Janda^{c,d}, Felix Creutzig^{a,b,e}^a Institut für Landschaftsarchitektur und Umweltplanung, Technische Universität Berlin, Straße des 17. Juni 145, 10623, Berlin, Germany^b Potsdam Institute for Climate Impact Research (PIK), Member of the Leibniz Association, P.O. Box 60 12 03, 14412, Potsdam, Germany^c Environmental Change Institute, School of Geography and the Environment, Oxford University, South Parks Road, Oxford, OX1 3QY, UK^d Minnesota Design Centre, University of Minnesota, Northrop Memorial Auditorium, 110, 84 Church St SE, Minneapolis, MN, 55454, USA^e Bennett Institute for Innovation and Policy Acceleration, University of Sussex Business School, Jubilee Building, Brighton, BN1 9SL, UK

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ABSTRACT

The skilled worker shortage in the installation trades constitutes a critical challenge to implementing low-carbon transitions globally, but the scientific attention to installers and their perspectives remains limited. This paper studies perspectives of craft entrepreneurs in four installation trades in Germany: roofers, electricians, heating installers, and painters. For this, it takes a novel mixed methods approach, drawing from interviews and an original survey of craft entrepreneurs ($N = 230$), co-created transdisciplinarily with craft stakeholders. It demonstrates that the skilled worker shortage manifests for craft entrepreneurs as a question of order prioritisation, rendering them pivotal gatekeepers who decide on transforming their enterprise towards low-carbon installations (LCIs), such as heat pumps, photovoltaics, or building insulation. We find that LCIs are likely to be deprioritised because they impose challenging change requirements on installation enterprises. Challenges relate to novel solutions, skills, work processes, business structures, economic calculations, and external framework conditions. The attractiveness of LCIs differs across trades and technologies, depending on LCIs' compatibility with business-as-usual practices, the concession of unskilled competition, and the order situation in alternative business fields. Crucially, for craft entrepreneurs, impediments to LCI provision result from the required changes in business practices rather than from a lack of installation-related skills. Our results show that the conventional organisational and business model of the skilled trades is reaching its limits in LCI provision, which requires more planning, consulting, cross-trade cooperation, bureaucracy, and digitalisation. Therefore, policymaking should expand its focus beyond the 'skills gap', facilitate organisational restructuring in installation enterprises, and improve the regulatory framework.

1. Introduction

Implementation challenges globally emerge as a priority for climate and energy policy [1]. While historically research and policymaking have focused on technology adoption by end-users [2,3], the installation sector is increasingly acknowledged as low-carbon transitions' rate-determining bottleneck [4,5], gatekeeper [6], or Achilles' heel [7]. Typically, the shortage of skilled workers and a 'skills gap' or 'mismatch' in the installation workforce are portrayed as the main challenges and addressed by policymaking [8,9]. For example, the European Commission's *European Skills Agenda* includes anticipating skill needs, updating training curricula, and funding training programs [10], as well as

launching the *European Solar Academy* in June 2024 [11]. The *Net Zero Strategy* in the United Kingdom pursues a similar approach [12].

However, this approach takes functionalistic, instrumentalist views on installers as 'workforce units', tasked with installing a determined technology with a certain set of skills [13], while giving little attention to their perspectives. Ample research has demonstrated installers' unique agency and capacity to make and execute decisions as middle actors [14–16], thereby 'making or breaking' low-carbon transitions [7].

Crucially, installing low-carbon technologies such as photovoltaics, heat pumps, and building insulation (hereafter referred to as low-carbon installations (LCIs)) at scales and rates consistent with climate targets requires involvement of already existing, incumbent, installation

* Corresponding author at: Chair of Sustainability Economics of Human Settlements, Sekretariat EB 412, Straße des 17. Juni 145, 10623, Berlin, Germany.
E-mail address: simon.wehden@campus.tu-berlin.de (S. Wehden).

enterprises [7,17].¹ These often offer a wider portfolio of services beyond LCIs [6], resulting in an enterprise-internal competition between LCIs and other services in times of skilled worker shortage and full order books (meaning bookings for installation services). Hence, enterprises' decisions on which services to prioritise are pivotal to the progress of low-carbon transitions.

However, although “understanding the roles, goals, and needs of these different actors, their perceptions and decision processes [...] is imperative in designing effective policies” [18], research on how installation enterprises prioritise orders and what barriers keep them from engaging (more) in LCIs is scarce. Therefore, this article aims to advance this understanding by studying the perspectives of craft entrepreneurs who are the crucial decision-makers in (mostly owner-managed) installation enterprises. Specifically, we focus on four ‘climate crafts’² and respective LCIs in Germany: rooftop photovoltaics (for roofers and electricians), heat pumps (for heating installers), and building envelope insulation (for painters). For that, we take an explorative mixed methods approach drawing from 29 qualitative interviews and an original online survey of 230 craft entrepreneurs in these climate crafts in Berlin and Brandenburg. For that, we ask the following research questions:

1. How do craft entrepreneurs prioritise orders?
2. How do craft entrepreneurs perceive LCIs?
3. What factors influence the (perceived) attractiveness of LCIs among craft entrepreneurs?

The article is structured as follows. The succeeding Section 2 provides background information on installers and the German context. Section 3 outlines and discusses our research approach and methodology. Section 4 presents the results, which are discussed regarding implications for future research, policymaking, and practice in Sections 5 and 6 concludes.

2. Background

2.1. Theoretical background: installers in low-carbon transitions

2.1.1. The installation step: a common blind spot in climate research

Research on low-carbon transitions remains largely oblivious to the installation step and its actors [15], focusing largely on technological potentials, innovation systems, and adoption of low-carbon technologies by end-users [2,3]. Individual perspectives, decision-making, and technology acceptance have mainly been investigated for end-users [5], while forecasting models of technology diffusion, such as agent-based models, merely include household behaviour, but ignore the decision-making of middle actors installing these technologies [6].

2.1.2. Installers can ‘make or break’ low-carbon transitions

Social science energy research highlighted installers' crucial importance for the physical implementation of low-carbon measures, including energy-efficient building retrofit [19], zero-carbon construction [20,21], installing heating systems [16] and rooftop photovoltaics [4,7]. Previous research referred to this group as tradespeople [17], craftspeople [20], or builders [21]. Globally, these vocational occupations face the largest shortages of skilled workers for implementing low-carbon transitions, already at current installation rates [8]. Depending on the geography, installers are trained in formalised apprenticeships and vocational education and training, for example, in Germany or

Scandinavian countries, while training in Anglo-Saxon countries tends to be less formalised and often occurs on-the-job [20–23]. Installers predominantly work in small-and medium-sized enterprises (SMEs), often owner-managed micro-enterprises with less than 10 employees, or as sole traders [16,17,19,24].

Studies recurrently highlight installers' unique *agency* (authority to make decisions) and *capacity* (ability to execute decisions) as middle actors in the context of LCIs [14,15]. These studies usually highlight three ways through which installers influence low-carbon transitions: first, by *advising* customers on different options [6,7,15,16], by *installing* technologies and making their own decisions during this installation process [6,7,15], and by *monitoring* and *maintenance*, securing operation post-installation [7,25]. Crucially, installers can *enable* or *disable* LCIs and energy-efficient operation. Thus, they are not, per se, facilitators of low-carbon transitions. Hence, to effectively accelerate the implementation of low-carbon transitions, “we must understand more about why [installers] choose to do the work they do” [17].

Ample research demonstrated that installers have their own agenda, perspectives, and motivations [2,15]. Studies highlight the importance of taking pride in the work [16,17], the satisfaction of carrying out a trade [16,20,24], and maintaining expert identities as good craftspeople [16,17,20]. This motivation to do a good job is also associated with strong customer orientation, aiming to make customers happy and be referred to for future work [6,16,17,24]. Customer orientation also manifests in the endeavour to save customers money, which can motivate installers to advise against LCIs with high up-front costs [6,17]. As business people, installers want to maintain viable businesses and reliably pay their employees, but they are not necessarily oriented towards profit maximisation or growth, perhaps preferring to carry out their trade themselves or rejecting the responsibility for employees [17,24]. In fact, working independently and experiencing autonomy are primary motivators for installers [17,24] who also gain professional pride from the ability to solve problems in self-responsibility. Some tradespeople are also motivated by the variety of activities and challenges to overcome in their trade, while others prefer to stick to the known [16,17]. Consistently, studies found installers' tendency to minimise risk by avoiding unknown practices and technologies [6,16,17,21,24,26]. Installers seek confidence in their offer to satisfy customers and to retain a good reputation. Additionally, installing familiar technology is more time- and cost-efficient than trying out novel technologies, thus contributing to the immediate viability of the enterprise [19]. While this risk-aversity may impede adopting new practices, many installers are also keen to gain this confidence, particularly through practical experience [21,26]. Personal interest and pro-environmental attitudes were repeatedly found to motivate installers to install and advise for LCIs [6,17,27]. Yet, there is evidence for ingrained structural conservatism in the sector owing to various path-dependencies, for example, in supply chain or customer relations, which lock enterprises into habituated practices [7,19].

2.1.3. Installers' challenges in low-carbon transitions

Various studies revealed challenges and change requirements that low-carbon transitions impose on installers' practices relating to the required technological solutions, activities, skills, work processes, and revenue generation.

LCIs involve several technological changes. First, single technologies such as heat pumps are quickly changing as they mature [27]. Second, technological solutions become more integrated, complex, and holistic, expanding beyond single technologies and traditional trade profiles, for example, from a focus on heating systems towards considering the building envelope [7,28]. Third, technologies become more digitalised [7]. Technologies' novelty and complexity reduce the applicability of previous experience and knowledge [6]. This constitutes a crucial impediment to installers who learn through practice, seek expert reputation, and minimise risks as highlighted above. Worries about durability, liability, and performance of new technologies and solutions deter

¹ We acknowledge that in some countries PV installations are performed primarily by new companies [29].

² Following an established nomenclature in research [4,5,22] and German discourse, we use ‘climate crafts’ as umbrella term for skilled trades providing LCIs.

installers from engaging [6,21]. Activities for LCI provision involve more planning and calculation [7,27,29], more cross-trade collaboration [4,29,30], more tuning [4,7], and more customer advice regarding novel technologies and beyond the traditional trade profile [7]. Accordingly, individuals need more cross-trade competencies, planning, and tuning [4,7,28], as well as digital skills [7] and ‘soft skills’ such as communication [7]. Thus, LCIs require (continuous) training and learning, but the skilled worker shortage reduces installers' motivation and time for changing practices [7].

Technological changes towards LCIs also imply changes in the organisation of work processes, business structures, and financial calculations. Previous studies examined these aspects from a business model perspective for PV installation enterprises [25,29] and low-carbon building retrofits [28]. Business models (BMs) can be described as “a means of commercialising innovative technologies” [25] or as an approach to diffuse technologies or services on a competitive market [28]. BMs comprise a value proposition to the customer, a supply chain of activities providing this value, and a financial model generating revenue from these activities [31]. These studies highlight the importance of enhancing and changing elements of BMs for LCI provision, including a value proposition based on energy services, specialised knowledge acquisition of support grants and training staff, enhancing planning and project management capabilities, integrating the supply chain or facilitating cross-trade cooperation, and offering low-cost financing mechanisms to customers. Specifically, the transition from piecemeal energy efficiency measures towards integrated whole-house approaches requires a change from the prevailing ‘atomised market model’ of separated single-trade businesses towards more integrated business models [28].

Lastly, various studies highlight the importance of regulatory framework conditions on LCI provision. Inconsistent and changing legislation, complex funding landscapes, fluctuating energy prices, and the instability in financial incentives constitute crucial deterrents for installers to change practices [6,7,25,27]. Besides the unreliability in regulation, the perceived burden of compliance with standards and legislation constitutes a crucial demotivator for providing LCIs [17].

In summary, existing research provided a comprehensive understanding of the installation sector, installers' pivotal influence on low-carbon transitions, their practices and motivations, and the challenges they face in low-carbon transitions. However, the existing research bears four main shortcomings. First, it is primarily qualitative, drawing from interviews, workshops, or ethnography, while mixed methods or quantitative studies remain scarce with notable exceptions [25,30]. Second, previous studies usually did not distinguish between different trades and technologies but rather focused on individual trades [16] or generally on building trades [21], with notable exceptions [4,5,7,22]. Third, existing studies provided little insight into the internal competition and prioritisation between services in the portfolio of incumbent installers, that is, the questions of order prioritisation and barriers to engaging in LCIs in times of full order books. Lastly, due to the sectors' heterogeneity, the transferability of studies to other locations is limited, calling for geographically more diverse research. Today, research on the German installation sector is very sparse [4,6], despite its international appreciation as a ‘high road’ country in low-carbon VET [13]. Therefore, this study advances the field by taking a mixed methods approach, including a large-N original survey, situated in Germany, and focusing on the decision-makers in installation enterprises from various climate crafts.

2.2. Empirical background: the German skilled crafts and trades sector

In Germany, most occupations involved in LCIs belong to the skilled crafts and trades sector, which is characterised by an internationally

unique degree and century-long continuity of self-governance, institutionalisation, and professionalisation [4,32].³ The sector is legally distinguished from industry and commerce and positively defined in the German *Craft Code* through a list of 130 state-recognised trades, which are described in a trade profile listing activities essential and non-essential to the trade. *Craft trades* require three to three-and-a-half years of formal dual training (where the responsibility for vocational schools lies with the state and craft self-governance assumes responsibility for apprenticeships and intercompany training)⁴ to acquire a *Journeyman Certificate* (German: Gesellenbrief). Thereby, essential activities of craft trades are also distinguished from ‘simple tasks’ (German: einfache Tätigkeit), which can be learned within three months and do not need craft training [33]. The trades are divided into Annexe A) *craft trades requiring a license*, for which a *Master Craftsperson's Certificate* (another one-and-a-half to two years of training) is obligatory for independent practice, Annexe B1) *craft trades not requiring a license*, for which a Master Craftsperson's Certificate is not obligatory but can be acquired, and Annexe B2) *craft-like trades*, which do not offer Master Craftsperson's Certificates. For Annexe A trades, essential activities must be performed by licensed enterprises, i.e. enterprises employing a master craftsperson (German: Meisterpflicht). Compared to most other European countries, the construction sector in Germany is not only more regulated, but also consists of fewer sole traders and micro-enterprises and has a higher share of skilled employees with VET qualifications [13].

All four climate crafts investigated in this study belong to Annexe A. However, no certification is required for installing composite thermal insulation systems and (until 2025) for mounting PV panels, although both are taught in the dual training for roofers and painters, respectively [34,35]. At the time of study, mounting PV panels without interfering with the roof substructure or façade construction was not classified as a craft activity, but a simple task or minor craft. In November 2024, PV installation was classified as an essential activity of the roofing, tinsmith, metalworker, and glasser trades (all Annexe A), thus, now requires licensing in a respective trade “to guarantee the safety and quality of installations and ensure that the energy transition is implemented by qualified companies.” (own translation from [36]). The electrical work of connecting PV systems to the grid must be performed by licensed electrician enterprises, the coating or plastering of insulation systems must be performed by licensed painter or plasterer enterprises, and heat pump installation requires services from licensed electrical and heating installation enterprises [33].

3. Methods

The following section presents our mixed methods and transdisciplinary research approach, building on expert interviews, group discussions, and a co-creative survey development in collaboration with craft stakeholders. The survey data, formulation of survey questions corresponding to the analysed variables, and R code are provided in the online Supplementary Material at https://osf.io/a4s27/overview?view_only=5f911073e41b4057ae77b2fd357bce1.

3.1. Emergent mixed methods design

We employed an explorative research approach with an emergent mixed methods design [37], which allowed us to adapt our empirical investigation to preliminary findings and opportunities emerging throughout the research process. Mixed methods research encompasses

³ For a detailed study on the role of craft self-governance in low-carbon transitions, see [4].

⁴ For a thorough differentiation of approaches to vocational education and training (VET) and contrasting understandings of skills and labour in German and Anglo-Saxon systems, see [13,23,47].

collecting and analysing both qualitative and quantitative data to gain more comprehensive views of the studied phenomena [38]. To our knowledge, our survey features the largest sample capturing perspectives on LCIs among various climate crafts, allowing for novel analyses such as inter-trade dynamics. Due to this methodical novelty, we place our analytical emphasis on the second quantitative phase (mixed methods notation: ‘qual → QUANT = explore and generalise findings’ [37]).

3.2. Qualitative part: interviews and transdisciplinary survey development

3.2.1. Data collection

The qualitative part consisted of two stages. Table A1 in the Appendix displays the interview sample.

In the first stage, between April 2021 and October 2022, we conducted 33 semi-structured expert interviews to identify priority areas for policymaking and future research. Initial sampling aimed to capture perspectives from all levels of the German craft system, while subsequent sampling was directed to clarify emerging aspects (see [4] for more information on this stage). Of these interviews, 15 were relevant to this research and included in the analysis. This stage revealed the decision-making and order prioritisation of craft entrepreneurs in the climate crafts as a priority research demand, given full order books. Additionally, we identified photovoltaics, heat pumps, and energy-efficient building retrofit as priority LCIs, particularly in view of official installation targets for these technologies on the federal level and in the state of Berlin. Accordingly, we focused the subsequent research on the climate crafts of electricians, roofers, and heating installers [4] and additionally included painters for building envelope insulation.

The second qualitative stage, between July and November 2022, was directed towards developing a survey questionnaire in co-creation with stakeholders, particularly craft guilds, trade associations, and Chambers of Crafts in Berlin and Brandenburg. We followed this transdisciplinary approach, first, to ground the survey in the existing knowledge of practitioners, second, to increase the likelihood of responses from this hard-to-reach population, and third, to increase the practical relevance of the results [39]. In this stage, we engaged with 14 additional representatives from local craft organisations and scientific experts through informational background interviews and two online group discussions. We documented the interviews through note-taking. During these conversations, we discussed interests and aims related to the survey (including our research questions), stakeholders' presumed answers to the research questions, and the specific survey items. Additionally, we gathered written feedback on the questionnaire via email, in shared documents, or directly through the comment function in a pre-test.

3.2.2. Data analysis

Interviews were recorded using the platform Zoom, transcribed verbatim using the software *NoScribe*, and subsequently checked manually. We analysed interview transcripts and notes from both stages through thematic analysis [40]. Using the software *Atlas.ti*, we coded arising themes inductively corresponding to our research interests: i) the role of craft entrepreneurs, ii) their strategies of order prioritisation, iii) change requirements of LCIs for installation enterprises, and iv) entrepreneurs' perception of these.

3.3. Quantitative part: online survey of craft entrepreneurs in installation enterprises

For the quantitative part, we surveyed craft entrepreneurs in four climate crafts in Berlin and Brandenburg: electricians, roofers, heating installers, and painters.

We deliberately focused the survey on Berlin and Brandenburg for two main reasons: first, the survey funding was provided by the *Climate Change Center Berlin Brandenburg*, a joint research centre researching both states and explicitly encouraging transdisciplinary research with

practice transfer [41]. The Berlin Brandenburg region is a particularly suitable research case because it resembles a typical geography of a densely-populated city (Berlin) surrounded by a rural region (Brandenburg), which can potentially become energy self-sufficient via renewable energy, mostly through photovoltaic [42]. Second, our own previous research suggested that collaborating with local guilds and Chambers of Crafts (instead of federal actors) facilitates access to enterprises and increases the credibility of the research among craft entrepreneurs [4]. A geographical focus was necessary to harness these strengths.

3.3.1. Survey development and pre-test

We developed the questionnaire in co-creation with craft stakeholders as described in section 3.2.1 and conducted a pre-test with eight experts and craft entrepreneurs to assess the survey's clarity, readability, and length. Subsequently, we implemented final refinements. The survey includes a general and a trade-specific part, which varies regarding the trade-specific LCI.

3.3.2. Data collection and sample

The online survey was implemented by the survey institute *Institut für Umfragen, Analysen und DataScience (UADS)*.⁵ Enterprises were contacted directly and individually via email and invited to participate. They were subsequently reminded via email and telephone to participate. Reminders specifically sought to deliver representativeness regarding trade and state. Contacts of enterprises were retrieved from business databases⁶ and enriched through web scraping contacts from the ‘craft enterprise search’ of the Chambers of Crafts, yielding an initial sample of 6907 enterprises. Additionally, the survey was announced in the general newsletters for member enterprises of the respective Chambers of Crafts and some guilds.

The online survey was open between December 2022 and March 2023 and yielded 230 complete responses. We excluded three responses due to particularly low completion times. Mean and median completion times were 29 and 22 min, respectively. The response rate of 4% is comparable to other studies in the sector, which were obtained for considerably shorter surveys [43]. The involved experts also emphasised that this response rate was higher than in their experiences. Table 1 presents the composition of the sample. The composition of the entire population of enterprises in the studied trades in Berlin and Brandenburg is provided in Table A2 in the Appendix.

As intended, the survey predominantly captures perspectives of craft entrepreneurs: 92% of the respondents are owner-managers or members of the executive board, as we had explicitly asked for in the survey invitation. Yet, due to the low response rate, we cannot regard the sample as representative. The institute realised representativeness in terms of state and approximated the proportion of trades, slightly oversampling roofers (18% in the sample compared to 11% in the population). This oversampling was deliberate to secure a robust number of responses for analysis ($n(\text{roofers}) = 40$). However, the considerable non-response bias probably resulted in an oversampling of enterprises interested in the survey content (LCIs, worker shortage, digitalisation) and with time capacities in the management. Vice versa, uninterested or overly busy entrepreneurs are presumably underrepresented in the sample. This bias is evident in the enterprise size in that our sample underrepresents microenterprises with fewer than five employees. Therefore, our analysis is restricted to patterns within this special but relevant sample. Crucially, we acknowledge debates on the expressiveness and appropriability of p -values when dealing with such unrepresentative samples [44,45]. However, we provide p -values in tests and regressions for the information of readers whilst emphasising

⁵ <https://www.institut-uads.de/>, last access: 17.12.2025.

⁶ Dun & Badstreet Database: <https://www.dnb.com/de-de/firmenverzeichnis.html>, last access: 17.12.2025

Table 1
Description of the survey sample.

	Accumulated		Electricians		Heating installers		Painters		Roofers	
	n	perc. [%]	n	perc. [%]	n	perc. [%]	n	perc. [%]	n	perc. [%]
Total State	227		65	29	77	34	45	20	40	18
Berlin	97	43	27	42	40	53	20	44	10	25
Brandenburg	127	57	37	58	35	47	25	56	30	75
No information	3		1		2					
Gender (male)	188	83	55	85	65	84	39	87	29	73
Craft entrepreneur*	208	92	60	92	71	92	42	93	35	88
Size categories [‡]										
< 5	78	37	19	33	31	42	19	45	9	24
5–9	74	35	18	32	28	38	13	31	15	41
10–19	33	16	9	16	8	11	7	17	9	24
20–49	16	8	4	7	5	7	3	7	4	11
> 49	9	4	7	12	2	3	0	0	0	0
No information	17		8		3		3		3	

	Mean ± s.d.	Median	Mean ± s.d.	Median	Mean ± s.d.	Median	Mean ± s.d.	Median	Mean ± s.d.	Median
Number employees [†]	11.6 ± 20.3	6	18.2 ± 29.2	7	10.0 ± 20.5	5	7.4 ± 7.5	5	9.3 ± 7.4	7
Craftspeople	8.5 ± 14.7	4	13.1 ± 21.5	4	7.0 ± 13.9	4	5.8 ± 6.4	3.5	7.6 ± 6.5	6
Administration	2.1 ± 4.4	1	3.1 ± 4.7	2	2.4 ± 5.9	1	1.1 ± 1.2	1	1.1 ± 1.1	1
Auxiliaries	0.9 ± 3.7	0	1.9 ± 6.9	0	0.6 ± 1.3	0	0.4 ± 0.8	0	0.5 ± 0.8	0

* Being the owner or a member of the executive board.

‡ Based on the number of employees. For comparability, we use the same buckets as the German craft statistics (see Table A2 in the Appendix).

† Calculated as the sum of the number of employed craftspeople, administration, and auxiliaries. For enterprises with zero employees, we re-coded the total number as 1. Participants might have understood the question asking for employed workers differently: presumably, some included themselves (the craft entrepreneurs) in the count, while some excluded themselves.

the limited generalisability to a larger population.

3.3.3. Quantitative analysis

We used *R* and *RStudio* for the quantitative analysis. Where the qualitative results suggested trade-specific differences, we used non-parametric Mann-Whitney-*U* tests to examine differences of ordinal variables elicited on 5-point Likert scales.

Subsequently, we employed ordered logistic regressions to further explore the relationships between the perception of *LCI unattractiveness* (Section 4.4.1), the current involvement in LCIs elicited as *turnover share LCI* (Section 4.4.2), and the self-rated competence in LCIs elicited as *grade* (4.4.3) as dependent variables, and various predictors as depicted in Fig. 1. We differentiate predictors into reasons for LCI unattractiveness (perceived barriers), structural factors facilitating LCI provision (positioning), and background factors associated with the enterprise or entrepreneur.

For each model, we examined the proportional odds assumption for ordinal regressions with Brant tests and calculated Variance Inflation Factors (VIFs) to control multicollinearity. VIFs were unproblematic, and the proportional odds assumption held for most models. Where the assumption was violated, we calculated different model specifications to examine the robustness of effects across models since the small sample size constrained releasing the assumption. In the case of *grade*, we transferred *grade* into a new variable *transition type*, ascribing enterprises with *grades* 1 and 2 to the level 'laggards', 3 and 4 to 'midfield', 5 and 6 to 'frontrunners', which yielded negative Brant tests.

Due to the relatively small sample size, we treat ordinal predictors and variables elicited on 5-point Likert scales as numeric variables.

To incorporate *climate attitudes* in our models, we calculated a mean score from five variables eliciting attitudes towards the low-carbon transition and the role of their enterprise and trade (see Fig. A2 in the Appendix and Supplementary Material). Cronbach's alpha ($\alpha = 0.81$) indicated good internal consistency, validating its use for the subsequent analysis.

We further constructed a *digitalisation index* capturing how many application areas an enterprise already uses digital tools (see *R* code).

We treated this *digitalisation index* as a proxy for enterprises' openness towards innovation and as a background factor facilitating the provision of LCIs (see [7]).

We modelled *LCI unattractiveness* elicited on a 5-point Likert scale using the regression formula (1)

$$\log\left(P\left(\frac{Y \leq j}{Y > j}\right)\right) = \alpha_j + \sum_{k=1}^n \beta_{j,k} \text{trade}_k + \sum_{l=1}^o \beta_{j,l} \text{barriers}_l + \sum_{m=1}^p \beta_{j,m} \text{background factor}_m \quad (1)$$

where $\log\left(P\left(\frac{Y \leq j}{Y > j}\right)\right)$ depicts the logarithm of the odds that the dependent variable *LCI unattractiveness* is in a category greater than *j*, compared to being in or below category *j*. α_j is the intercept for each category *j*. $\beta_{j,k}$ represents the coefficient for each trade *k* and $\beta_{j,l}$ the coefficient for each barrier *l*. $\beta_{j,m}$ represents the coefficient for different background factors *m*.

Analogously to *LCI unattractiveness*, we model the dependent variable *turnover share LCI* using ordinal logistic regressions as shown in formula (2).

$$\log\left(P\left(\frac{Y \leq j}{Y > j}\right)\right) = \alpha_j + \sum_{k=1}^n \beta_{j,k} \text{trade}_k + \sum_{l=1}^o \beta_{j,l} \text{positioning}_l + \sum_{m=1}^p \beta_{j,m} \text{background factor}_m \quad (2)$$

The same descriptions and assumptions apply as with *LCI unattractiveness* and formula (1), only with *turnover share LCI* as the dependent variable, and $\beta_{j,l}$ representing the coefficient for each positioning variable *l*. Here, we were interested in the structural factors determining the degree of current involvement in LCIs rather than which beliefs influence the perception of attractiveness. Hence, we included the same background variables in our model as for *LCI unattractiveness* but neglected the barriers. Notably, *turnover share LCI* was not elicited on a

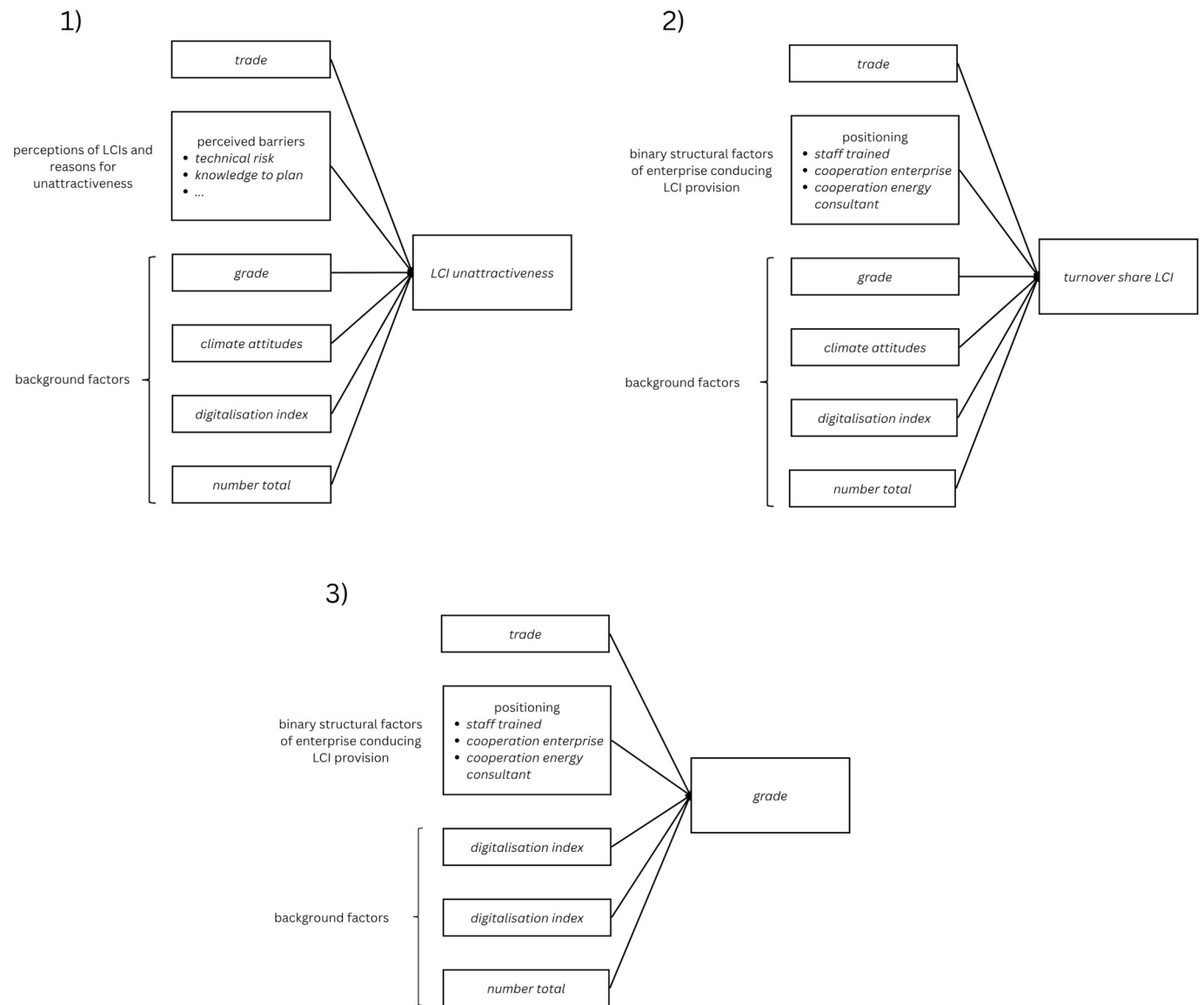


Fig. 1. Model structures for regressing *LCI unattractiveness* 1), *turnover share LCI* 2), and *grade* 3).

5-point Likert scale but on an ordinal scale where the different levels were not equidistant (“not at all”, “<25%”, “25%–50%”, “around 50%”, “50%–75%”, “>75%”). This limits the accuracy of the regressions.

Lastly, we also modelled *grade* and *transition type* using regression formula (2) since we were interested in the influence of enterprises' structural factors on their self-assessed competence.

3.4. Discussion of limitations

Our results should be examined in the light of three main limitations, which signpost trajectories for future research and which are briefly discussed hereafter.

First, the emergent study design and collaboration with stakeholders resulted in an explorative survey and quantitative analysis, rather than a deductive approach to testing hypotheses theoretically derived from the literature. In questionnaire development, we deliberately prioritised the experiences, realities, and interests of craft stakeholders, rather than existing theory. While this explorative and grounded approach is typical for novel research fields (cf. [46]), it also bears risks of overinterpreting seemingly ‘significant’ effects. However, it was instrumental for our

transdisciplinary approach, eventually yielding an unusually large sample size in this hard-to-reach sector.

Second, despite the relevance of the sample, its representativeness and size are limited. This constrains the generalisability of results and the scope of quantitative analysis. For example, the sample size impeded calculating robust trade-specific models, including trade-specific interaction terms and more predictors, or releasing the proportional odds assumption for models with positive Brant tests. Moreover, certain groups, such as sole traders or installers with little digital skills, are presumably underrepresented.

Third, the elicitation of some variables evoked inaccuracies and biases, specifically for *turnover share LCI* (not equidistant) and the number of employees (uncertainty about how to count the owner).

Hence, we recommend cautious interpretation of the statistical results and neither claim generalisability nor predictive power. However, we strived to examine the robustness of effects across model specifications, and the combination with qualitative data further increases robustness. Crucially, our study constitutes a unique exploration of relationships within a scientifically relevant and novel sample.

4. Results

Pre-note: craft entrepreneurs gatekeep low-carbon transitions through order prioritisation

Fundamentally, the interviews highlight the pivotal role and agency of craft entrepreneurs as gatekeeping bottlenecks in low-carbon transitions. Craft entrepreneurs as owner-managers often are the sole decision-makers and “*jack of all trades*” (S1110) in installation enterprises and decide which projects and activities to pursue, thus, how to prioritise orders. They prioritise activities and attention to issues crucial for their business's economic survival and have limited capacity for long-term strategy development. Therefore, their attention and attitude towards LCIs critically influence whether an enterprise gets involved. Crucially, the interviews reveal that the flipside of the much-discussed shortage of skilled workers is full order books for business-as-usual (BAU). Thus, entrepreneurs have little incentive to “*touch a running system*” (S114) and change their practices. Reiterating previous research, interviewees characterise craft entrepreneurs as avoiding complications and risks, sticking to established (habituated) practices, and striving to keep customers happy, save them money, and retain a good reputation. Our survey results further reveal that heating installers perceive heat pumps as not cost-effective for customers (see Fig. A4 in the Appendix).

The following section illustrates how craft entrepreneurs prioritise orders (4.1), corresponding to research question 1; it provides insights into entrepreneurs' perceptions of LCIs, research question 2, by demonstrating LCIs' varying attractiveness across trades and technologies (4.2) and by revealing change requirements imposed on business practices by different LCIs (4.3); and it answers research question 3 by analysing the relevance of factors for the (perceived) attractiveness of LCIs (4.4).

4.1. Prioritisation according to customer, service, scope, and extra efforts

Interviewed experts only provided “*gut feelings*” (S115) on how craft entrepreneurs prioritise, and the latter revealed different strategies and disclosed that they also decide “*at whim*” (S1113), without universal rules.

Drawing from our interviews, optional free-text answers of the

survey, and descriptive statistics, we found that entrepreneurs prioritise according to the questions ‘Who's the customer? What's the ordered service and material? What's the scope of the order? What's the effort beyond the core order?’. Fig. 2 presents the quantitative results, and Table A3 in the Appendix clusters the optional free-text answers according to these questions.

First, enterprises prioritise their regular customers, highlighting the strong customer proximity and orientation of craft entrepreneurs found in previous studies. Some process orders on a “*first-come, first-served*” (S1113) basis. Moreover, entrepreneurs avoid ‘complicated’ customers: one entrepreneur illustrated how she analyses customers' communication and demeanour to estimate whether they would “*cause trouble*” (S1112). She would rather turn down customers who are rude, pushy, or complain about other tradespeople: “*I don't have to do it.*” (S1112). Similarly, enterprises avoid customers with a bad reputation, such as public authorities, for example, due to delayed payments. The survey supports the interview findings. The *expected payment behaviour*, *regular clientele status*, and *appearance and reputation of the customer* constitute relevant factors for 93%, 76%, and 76% of the entrepreneurs, respectively. However, *chronological order* constitutes a relevant factor ‘only’ for 43%.

Entrepreneurs, second, prioritise orders with *services* fitting their business profile. 87% and 80% of entrepreneurs prioritise orders that fit their *core business activities* and bear little *expected complications*. However, estimates of project fit can be very different. For example, an entrepreneur of a construction enterprise illustrated that they “*focus on more complex and complicated work, where low-wage providers don't stand a chance because they don't have the know-how*” (S1111). Yet, also with complicated projects, entrepreneurs only get involved if they are confident in their ability to manage the complexity. Moreover, craft entrepreneurs prioritise projects based on the necessary *materials*. These considerations involve both the availability of materials, which constitutes a relevant factor for 55% of survey participants, and the choice of product brands (as illustrated in section 4.3.4). Specific to heating (and sanitation) installers, interviewees discussed switching enterprises' orientation from heating to sanitation. Several interviewees highlighted that as heating systems become increasingly complex, enterprises would prioritise sanitation projects, particularly since Germany's ageing

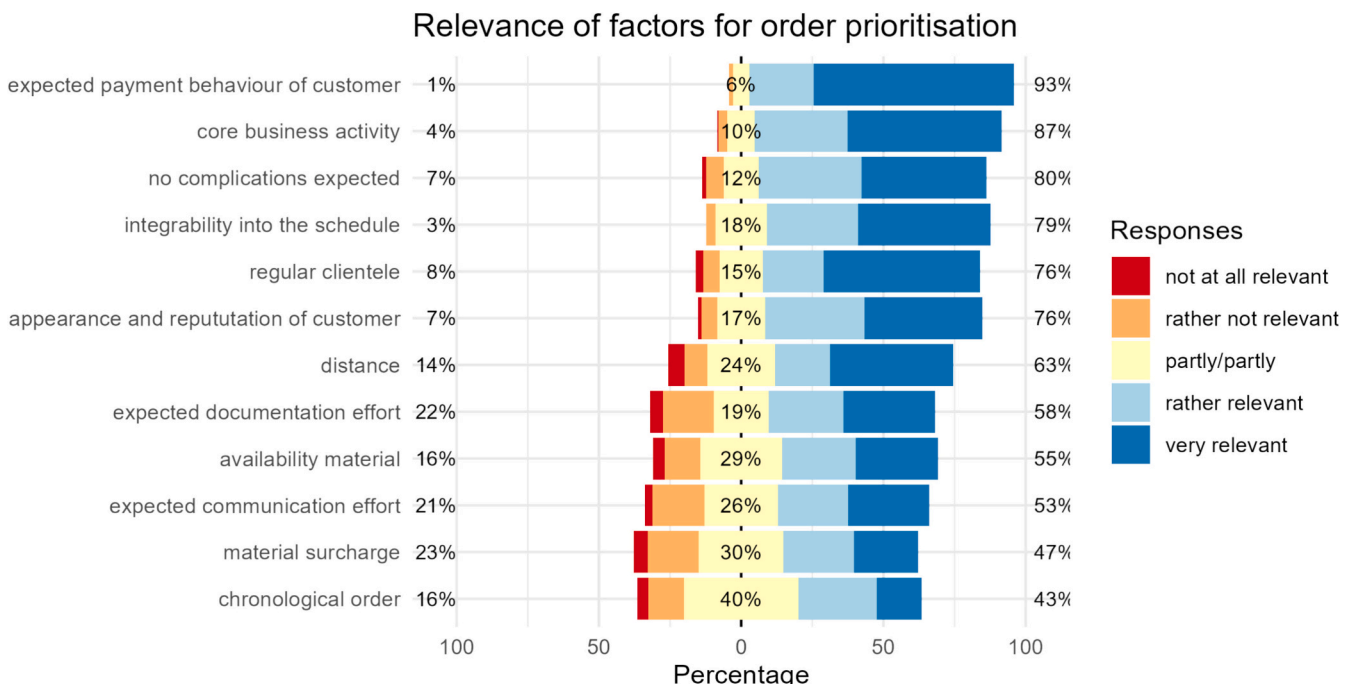


Fig. 2. Across trades, craft entrepreneurs prioritise according to customer, service, scope, and effort.

population increasingly demands renovation of bathrooms for accessibility. Yet, while a medium-term reorientation towards sanitation might be a plausible entrepreneurial decision, individual installers usually specialise either in heating or sanitation, rendering short-term shifts infeasible. Yet, this example shows that the opportunity costs of LCI provision are trade-specific, depending on the alternative business fields competing in the internal portfolio.

Third, enterprises consider the project's *scope* and time frame in that they must be “feasible” (S1111,12,13) in terms of staff capacity. The order's *integrability into the business schedule* also ranks among the most relevant factors, endorsed by 79% of survey respondents. Flexible time frames can be attractive for craft enterprises due to construction projects' characteristic unpredictability and delays. Thus, flexible time frames allow enterprises to shift workers from one project to another if delays occur, thereby optimising the deployment of the workforce.

Lastly, entrepreneurs seek to minimise the effort beyond the core order. One entrepreneur highlighted that enterprises avoid public tenders due to extensive reporting requirements. A representative of a painter association revealed that orders for well-prepared and arranged sites, for example, with issued scaffolding permits, are more attractive because tedious approval procedures increase the unpredictability of projects. Similarly, entrepreneurs minimise unproductive time, particularly commuting, and would reject orders if customers do not guarantee a parking space or if the distance is too long (see also Table A2). In the survey, extraneous efforts are perceived as less relevant but are still endorsed by most respondents. The *distance to the headquarters* and the *expected documentation* and *communication effort* constitute relevant factors for 63%, 58%, and 53% of respondents.

We only find a few differences between the trades as depicted in Fig. A1 in the Appendix. Drawing from our knowledge of the sector and previous research [7], we expected the *regular clientele* to be particularly important for heating installers due to the importance of maintenance contracts in the sector. Indeed, the survey results confirm this difference (87% endorsement among heating installers compared to 65%–74% in the other trades). Yet, the result of the Mann-Whitney-*U* Test suggests caution with generalisation ($p_{\text{regular clientele}} = 0.09$).

4.2. LCI attractiveness and involvement vary across trades and technologies

Our survey results further reveal that LCI attractiveness and enterprises' current involvement vary across trades and technologies. Fig. 3 and Table A4 in the Appendix show the degree to which enterprises are involved in the main LCI of interest (elicited as turnover share) and additional LCIs. To increase readability, we use the term ‘main LCI’ to refer to the LCI focused on in this paper: PV installations (electricians and roofers), heat pump installations (heating installers), and building envelope insulation (painters). Fig. 4 illustrates in how far enterprises perceive LCIs as an attractive business field, and Fig. 5 presents the openness to engage more in LCIs. The results reveal three main findings substantiating our qualitative results.

First, most surveyed enterprises are involved in the main LCI of their trade, but it constitutes only a minor share of their turnover. However, there is considerable intra-trade variation. For example, for 4% of heating installers and 7% of electricians, heat pump and PV installation accounts for more than 50% of the turnover, indicating a specialisation in the respective technologies.

Second, main LCIs are more attractive and common among roofers and heating installers than among electricians and painters. About three-quarters of heating installers and roofers are involved in the main LCI, but only half of electricians and painters (see Table A4). Similarly, roofers (57%) and heating installers (62%) are more open to extending their engagement in LCIs than painters (30%) and electricians (34%) in our sample. This different inclination between the trades also manifests in different attractiveness ratings as depicted in Fig. 4. While 55% and 58% of roofers and heating installers, respectively, find LCIs an

attractive business field, this pertains only to 25% of painters and 33% of electricians. The difference between roofers and electricians is remarkable since both responded to PV installation (see also section 4.3.4). Yet, Mann-Whitney-*U* Tests call for caution when generalising this result ($p_{\text{turnover share LCI}} = 0.07$, $p_{\text{LCI unattractiveness}} = 0.08$, $p_{\text{openness}} < 0.01$).

Third, also within a trade, LCIs are differently attractive and common. Installing EV charging infrastructure (‘wall-boxes’) is more common among electricians than PV systems, with 76% and 50% involvement, respectively. Similarly, 48% of electricians are open to engage more in the installation of wall-boxes and heat pumps compared to 34% for PV, although the Wilcoxon-Signed-Rank-Test suggests moderate reliability for the different openness between wall-boxes and PV ($p_{\text{openness wallbox/PV}} = 0.08$). For heating installers, heat pumps appear to be the most attractive and common LCI. 79% in our sample install heat pumps, and 64% are open to more, compared to 72% and 34% for solarthermic systems. Although not a heating technology, about a fifth of surveyed heating installers also install PV and indicate openness for more. As for roofers, building green roofs appears to be even more common than PV installation in our sample, provided by 82% and 72%, respectively.

Our qualitative results suggest that the attractiveness of different LCIs depends on their compatibility with existing business-as-usual (BAU) practices and structures and on the structure of competition in the respective field. For example, according to interviewee S215, installing wall-boxes is an attractive business field for electricians because the installation resembles BAU practices and imposes fewer change requirements than, for example, PV installation. As for market competition, the LCI attractiveness decreases for craft enterprises if the market is unregulated, allowing “too much unskilled competition” (roofer, free text survey response).

4.3. Low-carbon installations require multiple changes in business practices

The interviews reveal that LCIs impose several change requirements on enterprises compared to standard BAU practices, as compiled in Table 2. These can render LCIs unattractive for installers. Notably, the results particularly refer to the studied main LCIs. Based on the framework in Table 2, Table A3 in the Appendix categorises the text responses to the optional open-ended questions. Figs. 6 and A3 in the Appendix display the quantitative relevance of perceived barriers to LCI provision across trades and trade-specific, respectively.

4.3.1. LCI solutions: more complex, interrelated, and integrated

Generally, the LCIs studied are more complex, interrelated, and integrated than BAU solutions. Trivially, intervening in a building energy system to also optimise energy efficiency and carbon intensity, among other goals (costs, functionality, aesthetics...), is more complex than disregarding energy and carbon. This renders LCIs less foreseeable, more effortful, and riskier than BAU. Interviewees illustrated that optimising energy efficiency is not necessarily in the interest of installation enterprises because installers tend to ‘play it safe’ and avoid complications. Heating systems, particularly, are often oversized, thus inefficient, because installers want to save time, ensure the house gets warm, and satisfy customers. Interviewees refer to common practices, first, to replace broken boilers with new boilers of the same heating power irrespective of whether efficiency measures have been carried out, and, second, to stick to the factory settings of boilers because these practices are easier, thus time-efficient, than optimising the system for the individual context.

4.3.2. Skills: more cross-trade competencies, planning, and customer consultation

LCIs require competencies and activities beyond the traditional trade profile and habituated practices. Tradespeople may feel uncomfortable with these activities and refuse to change familiar practices they feel

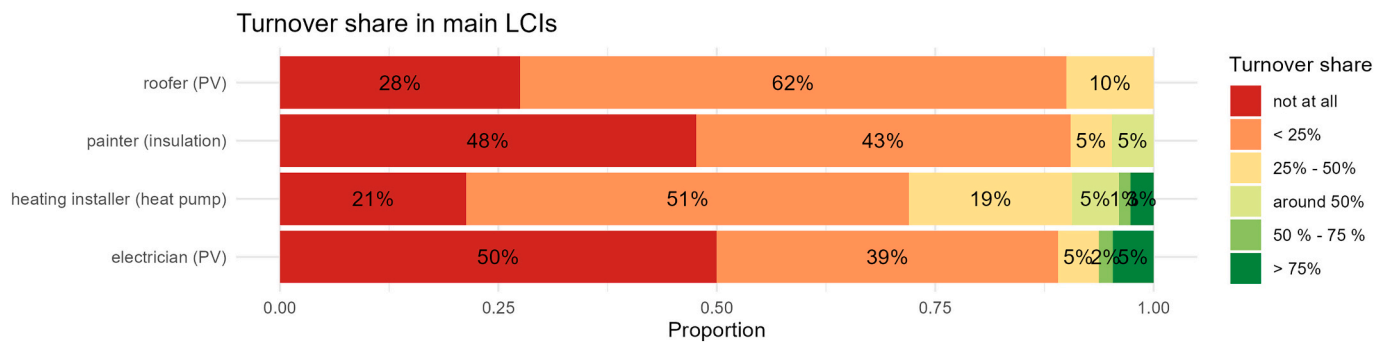


Fig. 3. Most enterprises, particularly roofers and heating installers, are involved in the main LCI, but it constitutes just a minor share of the turnover.

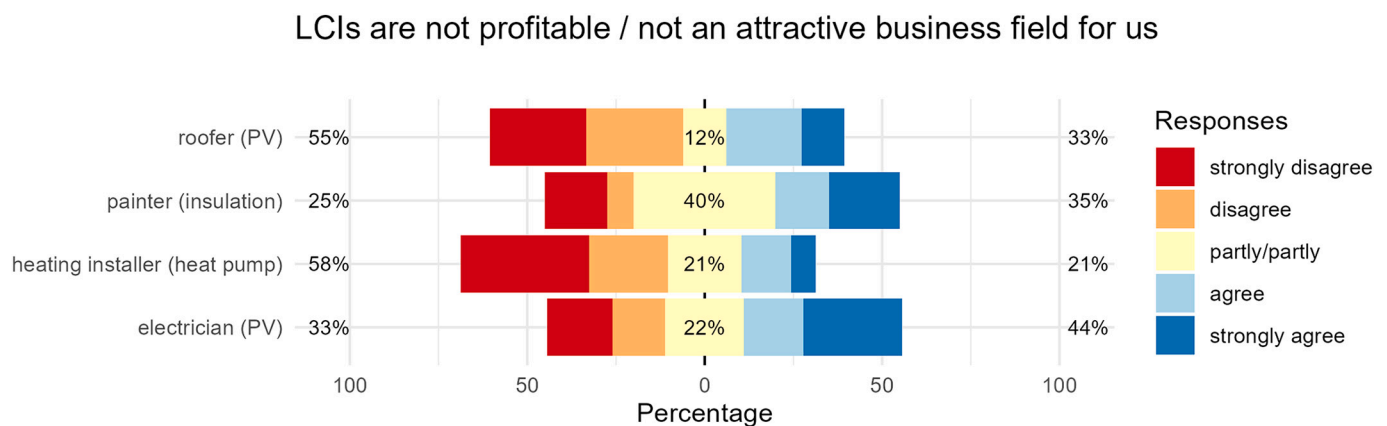


Fig. 4. The main LCI constitutes an attractive business field for most roofers and heating installers, but not painters and electricians.

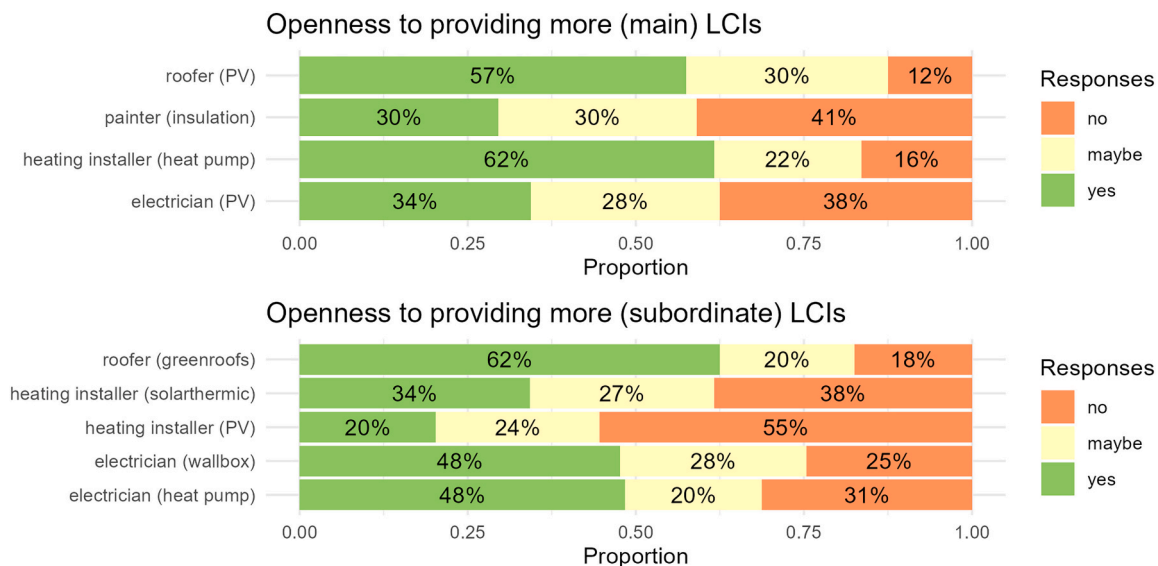


Fig. 5. The openness to providing different LCIs varies across trades and technologies.

confident with. Moreover, due to LCIs' higher complexity and risk, they require more thorough planning and customer consultation, also beyond standard practices in the trade. For example, one interviewee illustrated that "calculating wind loads is not standard practice for electricians" (S215), but it is necessary to install PV systems.

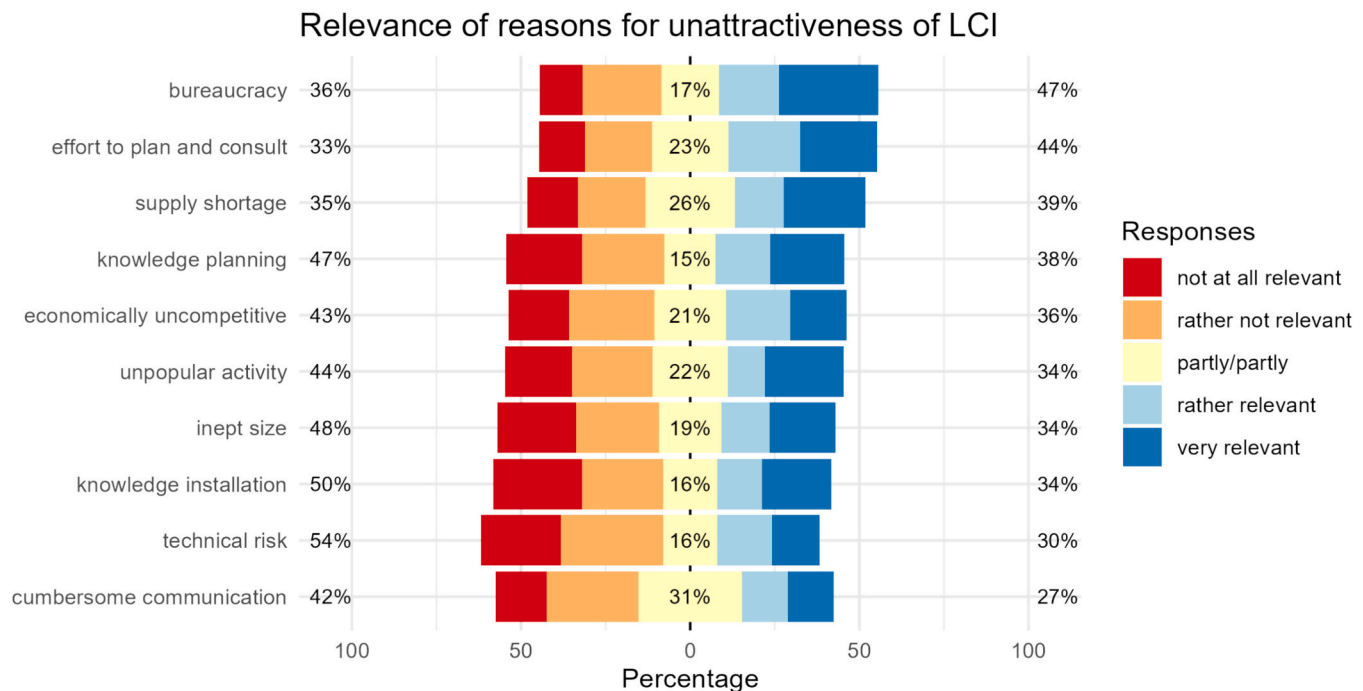
4.3.3. Work processes & business structures: more office work, communication, cooperation

Work processes and business structures of enterprises are often not suited for the increased planning and consultancy efforts of LCIs. These activities usually require the time of the craft entrepreneur or specialised employees (usually master craftspeople) since most employees (installers with a journeyman certificate) usually focus on practical installation. Additionally, LCIs often involve more bureaucracy (see

Table 2

Moving from BAU to LCIs requires changes in installed solutions, skills, processes, economic calculations, and external framework conditions.

	Business-as-usual (BAU)	Low-carbon installations (LCI)	Variable in the survey	Coincident studies
Assessment & evaluation criteria	functionality, energy services, costs, aesthetic	energy efficiency & carbon intensity additional part of the optimisation criteria		[28]
Solutions	- rather straightforward & siloed - single goal / few goals	- more complex, interrelated, integrated - multiple goals, including energy - less foreseeable, more effortful, riskier - more digitalised	- technical risk - digitalisation index	[7,28]
Activities, skills & competencies	- learned, practised, and established as part of trade profiles - focussed on individual trades - focussed on installation	- novel, alien to trade profile - more cross-trade competencies - more planning	- knowledge installation - knowledge planning - unpopular activity - staff trained	[4,7,27,29,30]
Work processes & business structure	- cross-trade cooperation is common, but many tasks are provided in individual self-responsibility - enterprises usually single trade - focussed on practical installation - small (administrative/planning) back-office	- more cross-trade cooperation is necessary, less individual self-responsibility - enterprises involve several trades - more planning and customer consultation (non-practical work) - more bureaucracy (reporting, approvals, grants...) - larger (administrative/planning) back-office required	- cooperation enterprise - cooperation energy advisor - effort to plan and consult - cumbersome communication - bureaucracy - inept size - economically uncompetitive	[7,28–30]
Economic calculation	earn money on journeyman hours and material surcharge	- monetarise planning and consultation - monetarise energy-efficiency (SHC: less profit with material surcharge) - unskilled competition in unregulated markets (not subject to licensing or certification)		[25,28,29]
External conditions	familiar supply chains and framework conditions	- novel and more complex supply chains - novel, potentially more complex and more dynamic framework conditions (increasing bureaucratic effort)	supply shortage	[6,7,19,25,27]

**Fig. 6.** Factors implying increasing office-work, including bureaucracy, planning, and consultation, constitute the most relevant reasons rendering LCIs unattractive across the entire sample.

4.3.5). Therefore, enterprises need to grow their personnel capacities for planning, customer consultation, and administration, which constitutes an economic investment and risk. Interviewees highlight that not all craft entrepreneurs are growth-oriented, and many prefer smaller, more manageable structures, which allow them to work practically instead of only doing office work. Thus, interviewees emphasised that it is less the

practical installation that deters companies from LCIs. Instead, they avoid the office-work (for themselves) or growing respective staff capacities to match the increased planning and consulting efforts and bureaucracy of LCIs. This finding is substantiated by the descriptive survey results displayed in Figs. 6 and A3 in the Appendix. Across the entire sample, the increasing importance of office-related work, such as

bureaucracy and the effort to plan and consult, constitutes the most relevant reason rendering LCIs unattractive, rather than installation-related aspects.

Additionally, LCIs require more cross-trade communication and cooperation with other enterprises. Managing these cross-trade intersections can be cumbersome and complicated, also requiring mutual trust. Although cross-trade cooperation is common practice in the sector, it constitutes a reorientation of practices for some enterprises. For example, gas boilers are often replaced by individual installers in independent self-responsibility. The increased need for cooperation can, thus, deter enterprises and tradespeople used to working independently, particularly sole traders. Some enterprises respond to this challenge by hiring master craftspeople and/or journeymen from other trades, thus integrating their supply chain.

4.3.4. Business calculations: earning through planning, consultation, and energy efficiency?

Traditionally, installation enterprises earn their money through the installation process, that is, working hours of journeymen and material surcharges, as depicted in Fig. 7. However, the increased effort for planning and consultation in LCIs requires enterprises to adapt their business calculations to make profit with services beyond installation.

Our interviews suggest that *material surcharges* are particularly important for heating installers, for whom it is common to buy products directly from manufacturers. Depending on the turnover made with a specific manufacturer, enterprises belong to different customer tiers, which are associated with different privileges, including discounts on the products or support services. This brand loyalty has two main consequences: first, installers prefer to work with products of manufacturers for which they are in a good customer tier. Second, heating installers calculate with considerable material surcharges. Since LCIs, such as heat pumps, are more time-consuming than just replacing gas boilers, heating installers sell fewer products per time and also get fewer discounts. Thus, they earn less on material surcharges, which may deter enterprises

relying on these. The survey results confirm that the *material surcharge* accounts for a larger share of profits for heating installers than for other trades: 44% of surveyed heating installers state that the *material surcharge* constitutes more than 40% of their profits, compared to 9%–21% in the other trades (Mann-Whitney-U Test: $p_{\text{material surcharge}} < 0.001$). For further illustration, 79% of surveyed heating installers calculate a material surcharge of 25–50% on gas boilers and 3%, even with a 50–75% surcharge.

Revenue generation from *journeyman hours* can also be difficult for LCIs involving simple, monotonous tasks and activities outside the *Craft Code*. First, these tasks can often be performed by un- or semi-skilled workers, who are more readily available on the labour market and have lower wages. As illustrated in section 4.2, LCIs are economically attractive for craft enterprises if they pay their high-skilled labour. Second, if such activities are considered ‘minor crafts’ and not essential to any trade, they can also be provided by any enterprise without needing to adhere to the *Crafts Code*, for example, to the obligation to employ a master craftsman. As introduced in section 2.2, this was the case for installing thermal insulation composite systems and mounting PV panels at the time of data collection and changed only for PV mounting in 2025. Therefore, installations of building insulation and PV systems are often provided by companies with un- or semi-skilled labour, often through subcontracting. In our case, subcontractors for insulation mainly come from Eastern Europe. In our survey sample, 90% of painters working with subcontractors primarily engage foreign companies. Consequently, painters in our sample struggle more than the other trades with low *economic competitiveness* in their LCI (Mann-Whitney-U Test: $p_{\text{competitiveness}} < 0.001$). However, although we had expected a similar phenomenon for roofers, due to their unskilled competition in mounting PV on rooftops at the time of data collection, PV was considered unattractive by electricians rather than roofers (see section 4.2). The free text survey answers indicate that perhaps the share of activities essential to the electrician trade is low in PV installation, making it hard for conventional electrician enterprises employing

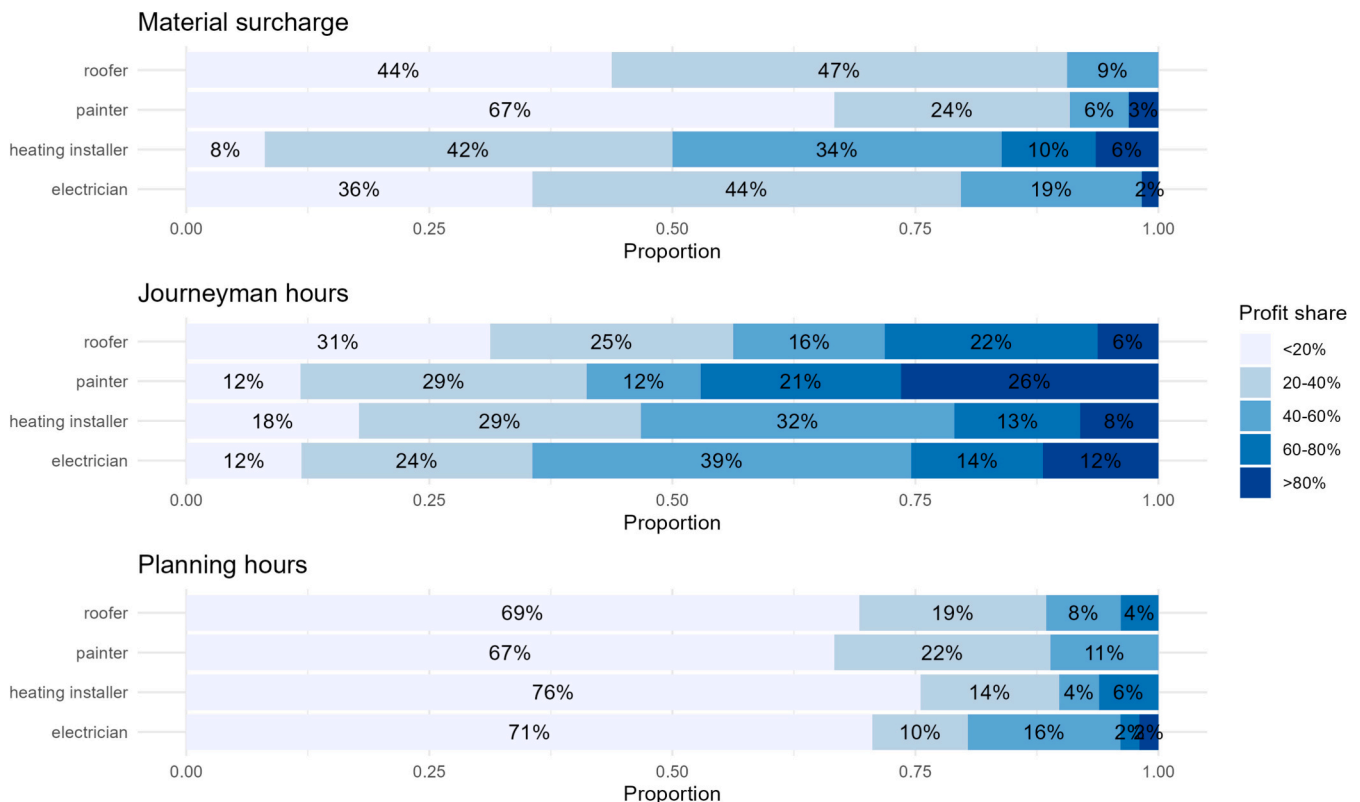


Fig. 7. Installation enterprises make their profit with *journeyman hours*, rather than *material surcharges* and *planning hours*.

primarily high-wage electricians to compete with specialised PV installation enterprises with a different (lower wage) workforce structure. Hence, electricians might restrict their involvement in PV to mere grid connection without engaging in planning and installing the systems.

Beyond competition by unlicensed enterprises, the emergence of large, debt-financed installation companies impacts the competitiveness of craft enterprises, particularly in PV and heat pump installation. With standardised solutions and industrialised processes, a focus on a few products, scaling effects when purchasing materials, and greater deployment of semi-skilled workers, these installation companies place price pressure on craft enterprises. According to the interviewees, this pertains particularly to the detached and semi-detached house sector. Moreover, they offer financing models with contracting and rental options to reduce the investment hurdles for customers. However, approaches such as heat or energy contracting, where installation enterprises supply customers with energy services instead of selling heating systems, are also pursued by ‘conventional’ craft enterprises, particularly larger ones, as suggested by our interviews.

4.3.5. External conditions and framework: novel, complex, dynamic

Finally, switching to LCIs involves changes in the framework conditions shaping installation, including supply chains and regulation influencing both the demand and provision of services. For example, since heat pumps are larger and more expensive than gas boilers, enterprises can stock fewer of them. Moreover, supply shortages and delays at the time of data collection reduced the attractiveness of the heat pump and PV business.

Crucially, interviewees portray the regulatory conditions for LCIs as ill-suited for craft enterprises, highlighting specifically the bureaucratic effort and the complexity and instability of framework conditions, including applications and subsidies, particularly for PV⁷: “The multitude of subsidies and their short-term nature are driving [installers] crazy. [...] If I want [installers] to commit to greater sustainability, I need stable, reliable and trustworthy framework conditions that give me a degree of certainty for the next 10 to 15 years” (S116). For PV, interviewees refer to the “solar coaster” (S1114) of unreliable conditions and demand when “politicians changed the framework conditions and installation rates collapsed completely [...] that destroyed a lot of trust.” (S113). Indeed, bureaucracy was considered a more relevant barrier for PV compared to the other technologies in the survey (Mann-Whitney-U Test: $p_{\text{bureaucracy}} < 0.001$).

4.4. Determinants of LCI unattractiveness, current involvement, and competence

The previous subsection describes changes and challenges imposed by LCIs, which can be perceived as barriers to LCI provision. To explore how these perceived barriers and other background variables actually influence LCI unattractiveness, we conducted ordinal logistic regressions using regression formula (1). Since the sample size restricts the number of predictor variables, we first present model results including all elicited barriers but not all background factors (4.4.1) and subsequently focus on background factors, including only a few barriers (4.4.2). Determinants of the current involvement in LCIs and of self-rated competence, analysed with ordinal logistic regressions using the regression formula (2), are examined in sections 4.3.3 and 4.3.4, respectively.

Owing to the predominantly qualitative research on installers and the expected methodological backgrounds of our audience, we present the results only briefly and provide more detailed information in the Appendix.

4.4.1. Regressing LCI unattractiveness as a function of perceived barriers

Reiterating the findings from section 4.2, heat pump and PV

installation are more attractive for heating installers and roofers, respectively, than PV for electricians. Avoiding LCI's *technical risk* is a prevalent predictor increasing LCI unattractiveness across all models, as is *inept size*. Crucially, the odds ratios and *p*-value of *inept size* stay constant even when controlling for the actual size of the enterprise (Model 3 in Table A5). Thus, the perception of being too small for LCIs is more relevant for perceiving LCI unattractiveness than the actual size. Moreover, the *effort to plan and consult*, *cumbersome communication*, and *bureaucracy* show considerable impact on attractiveness, with *p*-values below 0.1 in two of three models. Lastly, being *economically uncompetitive* is a relevant predictor for perceiving LCIs as unattractive. However, the informative value of this effect is limited since it gives little insight into the reasons for this low competitiveness. Tables A5 and A6 in the Appendix summarise the regression results.

4.4.2. Regressing LCI unattractiveness as a function of background factors and perceived barriers

Additionally, we constructed models focusing on the most relevant barriers and additional background factors. As barriers, we included *technical risk*, *inept size*, *cumbersome communication*, and both *knowledge* variables.

We derive several robust findings. First, *climate attitudes* are robust and relevant predictors of LCI unattractiveness, also overlaying the effects of trades. This suggests that the perception of and stance towards transformation influence the inclination to engage in LCIs rather than the trade, although the prevalence of transformation-friendly attitudes varies between the trades. Second, *grade* as self-rated LCI competence increases the attractiveness of LCIs, although the effect size and significance decrease when including different barriers (see Model 3 in Table A7). Thus, perspectives on LCIs are better predictors of LCI unattractiveness ratings than self-rated competence. Here, *technical risk*, *cumbersome communication*, and *inept size* all show robust effects on LCI unattractiveness at an α -level of 0.05. Lastly, neither *size (number employees)* nor the *digitalisation index* show reliable effects on LCI unattractiveness. Table A7 in the Appendix summarises the models.

4.4.3. Regressing current involvement in LCI as a function of structural factors

The results suggest current involvement in LCI, elicited at *turnover share LCI*, to be a function of competence, positioning, and mindset: *grade*, *training*, and *cooperation* (cross-trade with enterprises and with energy consultants), holding transformation-friendly *climate attitudes*, and a high *digitalisation index* (signalling both openness to innovation and a better positioning for LCIs) substantially increase the odds of being more involved in LCIs in our sample. The *number of employees* does not have a clear effect, given odds ratios of approximately 1 in all models. Tables A8 and A9 in the Appendix summarise the regression results.

4.4.4. Regressing competence in LCI as a function of structural factors

The results show that having the *staff trained*, *cooperating with another enterprise*, and *cooperating with an energy consultant*, as well as a higher *digitalisation index*, increase the odds of being in a higher competence category. Neither *climate attitudes* nor *number employees* clearly affect competence, given odds ratios of about 1 and *p*-values above 0.05 in both models. Moreover, roofers rate their competence worse than the other trades, *ceteris paribus*. Table A10 in the Appendix summarises the results.

5. Discussion

5.1. Scientific contributions

This study advances the research field of installers' roles in low-carbon transitions by making four main scientific contributions.

First, it highlights the gatekeeping agency of craft entrepreneurs who, in times of skilled worker shortage and full order books, decide

⁷ Interviews were conducted before the amendment of the Renewable Energy Act in 2023, which considerably reduced bureaucratic requirements for PV.

whether to transition their enterprise's operations towards LCIs. It reveals that LCIs compete with other services in the portfolio of incumbent installation enterprises and provides insights into the decision-making of craft entrepreneurs. Our results substantiate previous research by demonstrating craft entrepreneurs' desire to minimise risk and effort, maintain good customer relations, utilise their personnel capacities, and secure a viable business that reliably pays their staff.

Second, it synthesises a novel comprehensive framework of change requirements that LCIs impose on installation enterprises compared to business-as-usual (BAU), potentially reducing LCIs' attractiveness in times of full order books. We find the LCIs require 1) more complex integrated *solutions*, 2) cross-trade and novel *skills*, 3) different *work processes and business structures*, including more planning, consulting, and administration, 4) different *economic calculations* that generate revenue from these activities, and 5) different *external conditions* such as other regulations or supply chains. Whilst inductively generated from own empirical evidence, the framework serves as an integration of the dispersed literature and validates the existing knowledge for the German context, as shown in Table 2.

Third, it reveals considerable variation in LCI attractiveness across trades and technologies. Our evidence suggests that LCIs resembling BAU practices and imposing fewer change requirements, such as the installation of EV charging infrastructure, are more attractive to incumbent installation enterprises than substantially different LCIs, such as rooftop PV. Moreover, trades differ regarding the opportunity costs to LCI provision and the internal competition within enterprises' portfolios: the order situation and market conditions in alternative business fields of the respective trade determine the relative attractiveness of LCIs. Finally, in countries with a strongly regulated construction and skilled trades sector, such as Germany, policies regulating the concession of installation services substantially affect LCIs' economic attractiveness for incumbent craft enterprises: if regulation permits unskilled competition, relatively simple LCIs such as building insulation or mounting PV panels do not allow incumbent enterprises to pay their high-skilled labour.

Fourth, it demonstrates the relative importance of factors supporting or impeding LCI provision from the perspective of craft entrepreneurs. Crucially and contrary to the focus in the literature, for the gatekeeping entrepreneurs in our sample, LCI attractiveness is not primarily reduced by installation-related knowledge or 'skills gaps', but rather by change requirements related to business practices: the increased effort for consulting, planning, bureaucracy, and cooperation required for LCIs. The prevailing focus in research and policymaking on 'skills-gaps' and up-skilling the installation workforce may therefore be insufficient to boost LCIs in the installation sector, because it fails to recognise and cater to the "roles, goals, and needs of [the gatekeeping craft entrepreneurs], their perceptions and decision processes" (cf. [18]). However, avoiding LCIs' technical risk constitutes the most relevant predictor for LCI unattractiveness, indicating that enterprises may lack the ability to manage and minimise these risks. Thus, although entrepreneurs may not openly reveal skills gaps as barriers to LCIs, such gaps may manifest indirectly through risk-aversion or reservations if practical experience with these novel technologies is low, as found in many previous studies. Our results also hint at structural conservatism in the sector and highlight the importance of entrepreneurs' mindset. In our sample, entrepreneurs holding transformation-friendly attitudes and showing general openness to innovation through high digitalisation of their enterprises are also substantially more involved in LCIs. Finally, our quantitative evidence substantiates previous qualitative results in that enterprises with high competence and involvement in LCI are also more likely to have conducted the structural change requirements imposed by LCIs: they have their staff trained for LCIs, cooperate regularly with enterprises from other trades and energy consultants, and are more digitalised.

Lastly, although not part of our main analysis, descriptive results (see Fig. A5 in the Appendix) indicate that every fifth to third surveyed craft

entrepreneur often thinks 'I can't take it anymore' and considers abandoning the enterprise and leaving the trades. This snapshot of the mental state of crucial climate implementers should be an urgent warning to policymakers to seek to understand and improve their situation.

Overall, our results suggest that the conventional organisational and business model of the climate crafts is reaching its limits in LCI provision. Although the German context is special regarding the structure of its installation sector (fewer sole traders), its regulation (licensing), and its apprenticeship-based and qualification-focused dual training system, we find similar patterns as studies in other countries, concerning installers' motivations, perspectives, and challenges with LCIs. However, our results should not be transferred uncritically to different geographies, given the sector's diversity across social, economic, regulatory, and cultural contexts. Instead, our results increase the robustness of the scientific understanding of the installation sector and point to important factors potentially influencing the attractiveness of LCIs to craft entrepreneurs.

5.2. Implications of practice, policymaking, and future research

These results bear important implications for craft actors, policymakers, and future research.

Craft entrepreneurs should recognise the changes associated with low-carbon transitions and adapt their practices by optimising processes for consulting, planning, bureaucracy, and installation, and by developing cross-trade competencies and cooperation. Business models generating revenue from activities beyond mere installation, such as leasing or energy service contracts, can increase the economic viability of their enterprise in low-carbon transitions. *Craft associations* and *public intermediaries* such as energy agencies should extend their portfolio beyond installation-related upskilling programmes by supporting craft entrepreneurs in transforming their enterprises for LCI provision. Such programmes should include support with LCI planning, organisational restructuring, and developing practical experience to manage LCIs' technical risks and tackle the sector's widespread risk-aversion.

The intricacy of *policymaking* is to 'steer' the sector without losing it to alternative business fields. With exacerbating worker shortages and an ageing workforce, political aspirations to change practices in the sector go 'against the tide' and contrary to the sector's call for simplification and relief. Steering, thus, requires a careful balance of removing barriers (pull) and legislative 'pushes'. First, policymaking should reduce bureaucratic requirements and create a stable and reliable market and regulatory framework, rendering LCIs a 'simple' option regarding bureaucratic overhead and an 'unrisky' trajectory for business development. Second, policymaking can increase LCIs' economic attractiveness relative to other activities through reduced VAT rates. Third, upskilling programs should be directed more broadly to also include planning and organising LCIs. Subsidies for planning tools and programs facilitating cross-trade cooperation can further reduce entry barriers. Fourth, given various path dependencies locking enterprises into BAU practices (both *rationality* due to profitability and *irrationality* due to incomplete knowledge), legislative 'pushes' phasing out fossil technologies or commanding emission reduction standards may be required to effectively steer the sector towards LCIs. Crucially, economic incentives alone may be insufficient in a sector with strong motivations beyond profit maximisation and growth orientation. Although specialised enterprises already provide LCIs profitably, making the implementation of the energy transition an attractive business field across the sector is essential, first, to substantially increase installation rates, and second, to secure the energy transition's social license as a *Just Transition* through enabling (economic) participation for incumbent and novel actors. In this regard, our study also reveals ambivalent consequences of regulating LCI concessions, which is particularly important for countries with highly regulated installation sectors such as Germany. While a thorough discussion of LCI (de-)regulation is beyond the scope of this paper, policymakers should manage trade-offs, for example, regarding

installation quality, costs to consumers, social sustainability, or the equity of entrepreneurial opportunities in LCIs. For example, unlicensed enterprises and installation start-ups may accelerate installation rates, but do not contribute to the public good of dual education in Germany. Lastly, policymaking should explicitly fund research engaging with these hard-to-reach installation actors to tackle the bias in research, which accumulates knowledge in fields with high data availability and easy access to the field. This paper clearly shows there is much more to be learned regarding inter- and intra-trade dynamics in the sector.

Hence, *future research* in climate and energy studies should mainstream considerations about the ‘flipside of the plan’, that is, the perspective of on-the-ground installers. Larger samples would allow for more nuanced analyses of inter- and intra-trade dynamics, and studies in other locations would reflect geographical variations in this highly context-dependent sector. By taking analytical lenses from business, management, or organisational studies, future scholars can provide valuable information on how to address transition challenges for craft enterprises beyond the simplistic focus on ‘skills gaps’.

6. Conclusion

This paper takes a fundamental change in perspective, looking at LCIs not with the ‘helicopter view’ of pathway modellers but from the perspective of on-the-ground implementers. From this perspective, the flipside of the much-discussed skilled worker shortage in the skilled trades manifests as full order books, rendering craft entrepreneurs gatekeeping decision-makers, endowed with the *agency* to decide whether to transition their enterprise's operations towards LCIs.

Drawing from an original online survey of craft entrepreneurs in Germany, the paper constitutes one of the first mixed-methods studies in the field. It provides novel and trade-specific evidence for the decision-making of craft entrepreneurs, offering crucial insights for policymakers seeking to advance installation rates of low-carbon technologies. It shows that LCIs are likely to be deprioritised in times of full order books, because they impose challenging change requirements on installation enterprises. Crucially, to the gatekeeping craft entrepreneurs, LCIs are less a challenge of installation-related ‘skills gaps’, but rather of changing business practices. Organisational restructuring can increase LCIs' economic viability, as can improvements to the regulatory framework. Policymaking should therefore expand its focus beyond ‘skills gaps’ and seek to support the sector in transitioning its enterprises towards low-carbon installations.

CRedit authorship contribution statement

Simon Wehden: Writing – original draft, Visualization, Project administration, Methodology, Investigation, Formal analysis, Data curation, Conceptualization. **Kathryn B. Janda:** Writing – review & editing, Supervision. **Felix Creutzig:** Writing – review & editing, Supervision, Funding acquisition.

Declaration of Generative AI and AI-assisted technologies in the writing process

During the preparation of this work, the authors used *NoScribe* to transcribe interviews and *DeepL* in order to translate survey questions and interview quotes in German into English. After using these tools, the authors reviewed and edited the content as needed and take full responsibility for the content of the publication.

Declaration of competing interest

The authors declare the following financial interests/personal relationships which may be considered as potential competing interests: Simon Wehden reports administrative support was provided by BIT network of German crafts, roofing association Brandenburg, electrician

association Berlin-Brandenburg, painter association Berlin-Brandenburg. If there are other authors, they declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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Appendix A. Supplementary data

Supplementary data to this article can be found online at <https://doi.org/10.1016/j.erss.2026.104696>.

Data availability

Data and code are included in the online Supplementary Material, the link of which is provided in section 3 of the manuscript.

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