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DOI
10.1016/j.erss.2025.104290

Publication date
2025

Document Version
Final published version

Published in
Energy Research and Social Science

Energy Research & Social Science 127 (2025) 104290

Contents lists available at ScienceDirect

Energy Research & Social Science

journal homepage: www.elsevier.com/locate/erss

Original research article

Invisible hands in energy transitions: installers in the European post-industrial cities of Gothenburg and Rotterdam

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ARTICLE INFO

Keywords:
Transmission intermediaries
Energy transitions
Installers
Ecosystems
Post-industrial cities
Case studies

ABSTRACT

This paper focuses on the specific role of installers, a category of often overlooked diffusion intermediaries doing the actual implementation of energy transitions. We adopt an ecosystems perspective and aim to provide new knowledge on the installers' role in energy transitions, possible changes in this role, and the challenges installers face. Based on evidence from case studies in Gothenburg and Rotterdam, we first show how installers make or break energy transitions. They differ from other intermediaries in their long-term trust relations with customers, their deep contextual knowledge, and involvement in post-technology deployment. We unveil new nuances regarding downstream (installers deploy strategies to include budget-constrained customers in energy transitions) and upstream actors (installers face manufacturers' lock-ins and are trained by wholesalers and manufacturers). Secondly, we show challenges installers face caused by regulatory, market and technological dynamics in transitions, and identify new roles for them as *IT-specialists*, *manufacturers* and *holistic advisors*.

1. Introduction

National and local governments have formulated ambitious sustainability transition goals. However, these goals are hard to achieve due to challenges linked to 'just transitions', the broadness of transitions and other transition barriers [1,2]. One important barrier is a shortage of installers. European industry associations indicate the need for 500,000 heat pump [3] and even one million solar panel installers [4] by 2030 to meet the EU's renewable energy targets. Despite the desired energy transition, progress is already being hindered. In the Netherlands, for example, 36 % of job vacancies in energy transitions remain unfilled preventing progress in its energy transition [5]. Likewise, the deployment of ground source heat pumps in the United Kingdom is hampered by various barriers, including a lack of trained installers [6].

Installers are defined as "companies that provide installation and maintenance services" [7: 5–6] in various domains, such as insulation, electricity, and heating [8]. Most attention targets relatively new installers in the domains of solar PV and wind energy [9–12]. This paper focuses on incumbent electrical and heating installers ('installers' in brief) tasked with retrofitting of existing residential buildings.[1]

These incumbent installers are usually overlooked by researchers and policymakers because they tend to be small in size [13], work as subcontractors [14] and lack time to participate in research programmes [15]. Nevertheless, installers have an 'unseen influence' [13] in energy transitions due to their intermediary role between homeowners, governmental actors, and firms that have an upstream position in value chains [16]. Within this role as incumbent transition intermediaries [17], installers influence homeowners' decisions on what retrofitting measures to take and on how to use installed technologies. Thus, installers can script energy transitions [18], also in post-technology adaptation phases [19].

Despite growing awareness of their importance, installers still receive limited research attention [8,13]. Existing studies include theoretical conceptualisations of installers as intermediaries [20,21]. This intermediary role has been studied in empirical studies on factors that explain whether (or not) installers contribute to deployment and

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[1] We do not exclude PV installations as these are also provided by incumbent electrical installers. Outside our scope are start-ups in PV business.

https://doi.org/10.1016/j.erss.2025.104290
Received 13 February 2025; Received in revised form 8 August 2025; Accepted 13 August 2025
Available online 23 August 2025

scaling of retrofitting measures [8,13,16,22]. However, installers are often studied indirectly, focusing on the wider category of building professionals, retrofitting programmes and interactions with policy actors and downstream relations [7,13,23–26]. Only a few studies consider the installer perspective, including [16,18,27] who all investigate policies and downstream relations. Similarly, [28] put installers in the centre of their analysis of installers' learning in communities of practice, just like [8,14] who identify drivers and barriers of installers' deployment of heat pumps and smart home technologies respectively. Upstream relations with manufacturers are acknowledged in conceptual studies [21]. Likewise, their skills are regarded as a key factor explaining how installers affect energy transitions [13,16,25,27], but few studies focus on their learning and training [28,29] and broader capabilities [30].

We contribute to this to literature by adopting an ecosystems approach,[2] referring to a group of highly interdependent business (e.g., installers, manufacturers) and non-business actors (regulators and educational institutes) who depend on each other for survival [31,32]. We use this approach to explore interactions between installers and upstream and downstream actors, institutions and actors linked to installers' learning infrastructure. We aim to provide new knowledge and nuances on their role in energy transition and how it changes, and the challenges they face. Our study is guided by the following research questions: i) How do installers affect energy transitions; ii) what are their challenges, and iii) how are they affected by institutional, technological and market dynamics?

To answer these questions, we have conducted two empirical case studies, and combined transition frameworks [33–35] with literature on transition intermediaries (e.g., [17,19] and installers [28]). We explore these interrelated fields of literature to make theoretical arguments on the importance of installers and how they differ from other intermediaries, and to discuss the dimensions we use to structure the empirical results: *actors*; *institutions*; *skills*; *technology*.

We have elucidated two qualitative case studies on installers in the European cities of Gothenburg (Sweden) and Rotterdam (the Netherlands). We have conducted 54 in-depth interviews with installers (9) and other actors in their ecosystem, including institutions (e.g., industry associations) (9); utilities (2); training and research providers (12); manufacturers, wholesalers and software providers (8); public authorities (9); housing corporations (2); other (3). We focus on installers dealing with the retrofitting of existing residential buildings. This task is key for CO_2 reduction ([16]; e.g., nearly 40 % of the total energy consumption in Europe takes places in homes and premises [36]). This helps us collecting insights into the installers' challenges when integrating relatively new technologies (e.g., thermal heating) with legacy installations and infrastructures (district heating). Finally, we explore the retrofitting of social housing buildings and provide new nuances on how installers affect 'just' (or 'inclusive') energy transitions [2,37,38].

The rest of this paper is structured as follows. Section 2 discusses the existing literature on installers and introduces our analytical dimensions. Section 3 details our method, followed by the empirical results and debate in Sections 4 and 5 respectively. The last section (Section 6) concludes.

2. Literature

2.1. Installers

Installers work in various domains, such as insulation, roofing, heat pumps and PVs [8]. These domains indicate a large heterogeneity of installers who differ in technologies, utility domains (water, energy, heating) and skills (e.g., a central heating installer can do the work of a plumber, but not the other way around [28: 43]). Another differentiation is that between 'retrofitting' and 'repair, maintenance and improvement' of buildings, whereby retrofitting explicitly aims to increase energy efficiency by adapting a building's physical fabric (or 'building envelope') or energy services within it [21: 1]. Therefore, retrofitting encompasses measures to reduce energy- and heating demand and to create net-zero buildings through higher efficiency (e.g., insulation); microgeneration of heat (solar thermal systems) or electricity (PV cells) [16].

Despite their heterogeneity, installers share key characteristics. They employ craftspeople who informally obtain their skills on the job through learning-by-doing and interacting with supervisors and peers within their community of practice [28]. Moreover, installers often work as sub-contractors in temporary projects [21]. Finally, installers are mostly micro-enterprises that primarily work alone or in small teams and change location on a regular basis [13]. These latter characteristics explain why installers are largely invisible to policy actors and researchers.

2.2. Installers can make or break energy transitions

Installers play a direct role in energy transitions by providing retrofitting services [16]. Accordingly, poor installation work hinders successful energy transitions [29] and can result in negative impact, such as fires caused by wrongly installed PV systems [39]. Installers can also reduce negative environmental impacts of renewable energy technologies during the construction, installation and demolition phases [9], thus indicating their importance across the lifetime of installations.

Indirectly, the influence of installers is even larger due to their role as transition intermediaries (see Fig. 1), which encompasses agents who connect actors to positively affect sustainability transitions [19: 1072]. The initial transition literature already stressed the need of systemic intermediaries in early transition stages to achieve sustainable development [40]. Later, scholars have moved beyond the niche stage and show the importance of intermediaries to overcome system failures in later transitions stages [41]. This has led to new conceptualisations and typologies (e.g., [17,19]).

One conceptualisation differentiates intermediaries specialised in intermediation from unspecialised intermediaries who also conduct other activities (e.g., manufacturing) [42]. Unspecialised intermediaries, including installers, may perceive conflicts between intermediation and other activities that impede energy transitions. Furthermore, intermediaries can fulfil various roles in sustainability transitions, including networking; brokering; learning; innovation and diffusion; policy implementation and lobbying [17]. These roles can be fulfilled by different actors [43], including public agents, such as municipalities and energy advisors, who translate national policies to local citizens [43,44]. Individual firms and industry associations can also act as intermediaries between technology providers and governmental institutions and/or users [17]. Furthermore, new actors (e.g., energy coaches) and existing players (architects) can evolve into intermediaries [19]. The latter have a dual transition challenge as incumbents have to change their own existing technological and institutional context [17]. Accordingly, incumbent intermediaries tend to be locked into their existing landscape, thus impeding transitions. However, incumbents are also willing and able to stimulate change [17]. Likewise, profit-oriented intermediaries do not always prioritise profit-maximisation, thus reducing conflicts between actors hindering transitions [11]. Taken together, the degree to which intermediaries positively or negatively affect transitions depends on how they conduct their activities.

Installers are consequently diffusion intermediaries with a large effect on energy transitions and differ from other transition intermediary types. Firstly, as installers visit households at home, they obtain contextual knowledge on users (e.g., available budget) and the building envelope [13,18]. That gives them the upper hand vis-a-vis upstream

[2] We use the generic term 'ecosystem'. It goes beyond this paper to discuss the various types of ecosystems.

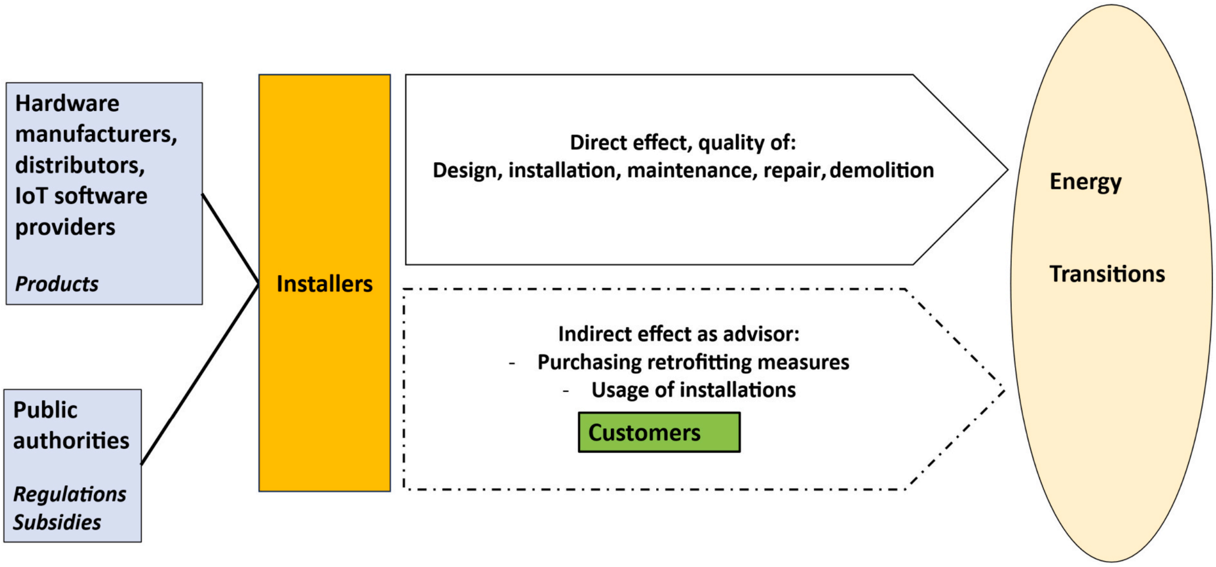

Fig. 1. Installers' direct and indirect (dotted line) role in energy transitions.

actors on new technology deployment decisions [21]. Downstream in value chains, installers advise homeowners on what retrofitting measures to take [28,45]. Due to the high complexity of installations, homeowners have limited knowledge and rely on the installers' advice [8,13]. Secondly, installers have long-term trust relationships with their customers [8,25]. Accordingly, and to avoid additional costs for hiring specialised advising intermediaries (e.g., energy consultants), customers nearly always follow the installers' advice [24: 57]. Finally, installers advise homeowners on *what* technologies to utilise and *how* to utilise them [28]. This advice may sometimes affect the energy transition negatively. For example, instead of switching heating installations to lower temperatures to save energy, installers may advise households to keep heating installations running on a constant higher temperature to reduce the risk of call backs [18].

Thus, installers can advise against retrofitting [16]. Whether installers positively or negatively affect retrofitting depends on various factors, including installers' capabilities, customers' perceptions and trust, and installers' portfolio [8,13,16,22,26]. This paper does not provide an overview of these factors (see [8,13]): rather, it aligns our findings with existing literature and adds new nuances regarding installers' (changing) role and challenges.

2.3. Analytical dimensions

We define and operationalise three analytical dimensions of socio-technical systems – actors, institutions and technology [33,34]. Moreover, following [21] we add 'skills', given the importance of installers' capabilities as a key factor affecting energy transitions.

2.3.1. Actors

We define actors as people and organisations involved in transitions [21], and we follow a value chain logic and differentiate between upstream and downstream actors [35]. Installers intermediate between these (cf. Section 2.2). Installer literature provides limited attention to *upstream actors* (manufacturers, wholesalers, engineering consultants) and provides contrasting hints on the installer-upstream actor interaction. On the one hand, installers have power vis-a-vis upstream actors due to installers' direct access to households [21]. On the other hand, manufacturers provide warrantees and training, suggesting dependencies on manufacturers. *Downstream actors* in the context of retrofitting encompass homeowners, landlords, social housing providers and households [46]. Downstream relations are more widely discussed in the literature on installers as advisors (cf. Section 2.2).

2.3.2. Institutions

Institutions encompass "structures through which norms are developed and manifest" [21: 147]. Institutions should not be limited to public organisations [33] and include various aspects, including policy making, certification, regulations and norms [21]. Energy transitions require changes in existing institutions [1], that in turn, as we show in this paper, affect installers.

We explore two sub-dimensions affecting installers' influence on energy transitions. The first sub-dimension encompasses *policies and regulations*. Section 2.3 highlights how the gap between policy actors and installers hinders installers' ability to provide proper advice [13]. Inconsistencies in governmental regulations also negatively affect installers' role in the diffusion of retrofit measures as they hinder the provision of good advice and may weaken the trust-based relationship between installers and homeowners [27]. The second sub-dimension, *certification*, has had limited attention in the literature, which might be explained by the absence of certificates in many European countries [9]. However, certificates are important to safeguard quality in energy transitions but may also result into negative effects we show in this paper.

2.3.3. Skills

We use three sub-dimensions to operationalise skills. For *skills type*, we differentiate between technical and non-technical skills [28]. Technical skills relate to craftmanship, i.e., high quality workmanship and diagnostic ability to solve problems. These skills refer to product-oriented knowledge on the functioning of selected technologies, and the installers' abilities to design and install these [28]. Hence, these skills affect the quality of installations, with poorly designed and installed installations negatively affecting energy transitions [29]. Non-technical (or 'soft') skills are linked to installers' abilities to interact with customers [28]. These skills are thus important for installers' role as advisor. The *learning mode* is the way in which installers obtain their knowledge. They mainly obtain their skills through informal learning-by-doing and interaction with supervisors and peers [28; cf. Section 2.2]. Accordingly, formal *training infrastructure* is less relevant [29]. Formal training is offered by various actors, including vocational schools, manufacturers and associations [9]. However, such courses are often not approved by national bodies, and accordingly, lack standardisation and vary in quality [9]. Moreover, manufacturers' lack of installers' craftmanship may hinder the effect of manufacturers' training [27]. Hence, these challenges in formal training may affect energy transitions negatively.

2.3.4. Technology

Transitions encompass deployment of and changes in technologies connected within larger systems [1]. Here, we distinguish various *technology levels* that we use as first sub-dimension to explore how installers influence technology deployment. Single technologies are individual artefacts [1], such as heat pumps, that installers connect to in-house heating and electrical systems (e.g., connections of heat pumps to radiators). The energy-performance of these systems depends on the building envelope [16]. The building envelope, at its turn, is connected to urban utility infrastructures, such as electricity grids [47].

Beyond physical technologies, we add '*digitalisation*' as a sub-dimension, given the importance of the twin transition towards a green and digital future [48] and the development of smart utility infrastructures. We explore installers and digitalisation and the effect on energy transitions in two ways. First, installers influence deployment of digital technologies. For instance, installers may introduce digital heating controls mainly to tech-savvy users and not to less digitally skilled customers [18]. Second, and in the other direction, digitalisation may affect installers' work practices as indicated, by way of comparison, in new roles of civil engineers in smart cities [49].

Installers play a key role in technology deployment as they are the actors who design and select technologies and advise households on what retrofit measures to take (cf. Section 2.2). We introduce new nuances to this role and explain how installers are affected by dynamics in digitalisation, new technologies and interactions between different technology levels.

Table 1 summarises the (sub)dimensions that we use to structure our empirical results. The dimensions are interrelated. For instance, new technologies and certification require new skills.

Table 1
Analytical dimensions.

Main dimension	Sub-dimensions
Actors	- Upstream - Downstream
Institutions	- Policies and regulations - Certification
Skills	- Types - Learning modes - Training infrastructure
Technology	- Technology level - Digitalisation

3. Method

3.1. Research design

To explore how installers affect energy transitions and the challenges they face, we conducted case studies on installers in Gothenburg and Rotterdam. We selected these European cities as the continent has set strict climate goals to realise a green and digital future [48]. However, Europe is also challenged by a fragmented retrofitting market [50] and energy poverty, both hindering energy transitions. The latter has become even more important due to the Russo-Ukrainian War that drives an energy transition away from insecure and fluctuating commodity prices. A key element to realise this transition is retrofitting [51]. Secondly, both are post-industrial cities facing larger challenges to achieve their sustainability goals than service-oriented cities. Moreover, post-industrial cities face high electricity demand, adding pressure to the electricity grids beyond the impact of population growth. At the same time, specific industrial utility infrastructures, such as district heating, enable energy decarbonisation at scale, offering benefits of affordability, increased efficiency and flexibility of storage of heat and electricity [52]. These specificities of post-industrial cities help to elucidate the relations between installers and energy transitions, particularly regarding the institutional and technology dimensions. Thirdly, both cities are confronted with energy-injustice [38,53–55] which helps us to explore the role of installers in just transitions. Fourthly, the cities differ in other aspects, including the sustainability transitions and governance structures (see Table 2). In maximising variety in these other aspects, we aim to analyse empirical regularities on the role of installers and challenges in energy transitions.

3.2. Data collection and analysis

The primary data for this study were gathered through 54 in-depth interviews, totalling 58 interview partners (i.e., some interviews included two interviewees) and two validation workshops (see Table 3 and Appendix A that also explains the interviewees' IDs). Interviewees represent a large diversity of actors in the installers' ecosystem, allowing us to advance our understanding on how institutional, market (demand-side actors) and technological dynamics (upstream actors and researchers) affect installers. We interviewed 6 small and 3 large installers. In Gothenburg, we conducted only one interview with an installer, but this bias was reduced by interviews with industry associations. Moreover, two interview partners worked as installer before, but changed their position. Likewise, we did not interview software providers in Gothenburg but could still cover the effect of digitalisation on installers by interviewing a former founder of a smart building platform, researchers working on smart energy systems, and representatives of an Internet-of-Things (IoT) firm during our workshop. 21 interviews were done in-person, the rest online. The interviews lasted on average sixty minutes.

The semi-structured interview guide consists of questions on: i) installers' challenges; ii) installers' practices (input and technology sourcing; installation work; learning and innovation; customer interaction; interactions with peers, competitors and industry associations) and how these practices affect energy transitions; iii) effects of digitalisation; iv) policies and regulatory dynamics (see Appendix B).

We validated our findings during a workshop in each city,

Table 2
Characteristics case studies.

	Gothenburg	Rotterdam
Sustainability goals	Net-zero climate footprint 2030	Climate neutral 2050
Policy focus	Environmental sustainability	Affordable energy and reduction energy poverty
Sustainable transitions	Increase energy- and heating efficiency	Increase energy- and heating efficiency Natural gas phase-out: replace gas boilers with full electric or hybrid heat pumps (the latter combines gas with electric heating), or other heating technologies
Energy and heating infrastructures and governance	Energy and heating generation and distribution by the municipal firm Göteborg Energi	Energy generation by private firms Energy grid operated by the public firm Stedin District heating network operated by private firms
Social housing	Not existing, universal public housing, provided by municipal housing corporations Well-insulated buildings, largely built within the Million Housing programme (1964–1974)	Provided by private housing corporations Well-, but also poorly-insulated buildings The latter largely built in (post-)war period (1940's-1970)

Sources: [56–58].

Table 3
Fieldwork.

Type	Gothenburg			Rotterdam		
	Interviews	Interview partners	Workshop participants	Interviews	Interview partners	Workshop participants
Installers	1	1	0	8	8	1
Industry organisations and other institutions	5	5	0	4	3	1
Utilities	2	2	1	0	0	0
Training, education, research	7	8	2	5	7	4
Hardware manufacturers, wholesale, engineering consultants	3	3	2	3	3	0
(IoT) software providers	0	0	2	2	2	1
Public authorities	3	4	0	6	7	0
Housing corporations and citizens' collectives	1	1	0	1	1	2
Other	0	0	0	3	3	0
Total	*22*	*24*	*7*	*32*	*34*	*9*

complementing our interview data with field trips to a district heating company in Gothenburg and living labs in Gothenburg and Rotterdam/Delft. We participated in two sessions of an energy transition learning community in Rotterdam and paid a two-day visit to an installers trade fair in the Netherlands, where we took an ethnographic approach by exploring interactions between installers and upstream actors. This visit helped us to gather additional data in short interviews with visitors and exhibitors. Finally, we conducted two follow-up interviews with representatives of the Dutch and Swedish industry associations to gain more insights on prefabrication, energy injustice and installers' reputation and trust.

We audio-recorded the interviews and took detailed notes of six interviewees who did not provide permission for recording, and during the workshops, network meetings and field trips. We anonymised research participants through IDs and complied with the ethical regulations of our university. Recordings were transcribed and analysed with codes based on the (sub)dimensions of our study: actors, institutions, skills and technology (see Appendix C). We triangulated primary with secondary data, including reports by industry organisations; installers websites; installers media; existing literature on the case studies and policy documents.

4. Results

4.1. Actors

4.1.1. Downstream actors

In both case studies, installers have long-term trust-based relationships with customers. This mutual trust is based on face-to-face interaction and personal visits: "An installer is a traditional tradesperson. Actually, the last one who still visits people at home … So, he has a high level of trust among households and homeowners" (R14). Likewise, interviewee G7 mentioned that households build other relationships with electrical installers than with other tradespeople "as you meet this person more often". From the installers' perspective, building trust and keeping a good reputation is important. For instance, installers indicated that they "have a large responsibility to customers" (R27) and still visit customers for acquisition rather than doing online intakes (R25). Trust is thus important for acquisition which mainly takes place through mouth-to-mouth advertisement according to our interviewees.

Customers, at their turn, rely on installers' expertise regarding complex technologies, even though normally advise on single technologies, such as gas boilers. However, the energy crisis caused by the Russo-Ukrainian war, has increased customer demand for holistic solutions. This implies advice beyond a single technology and increases the risk of mistakes. The crisis put pressure on installers due to a sudden increase in demand for energy saving measures, e.g.: "Yeah, it was extreme, and everyone wanted to fix their windows" (G12a). "Everybody should do everything now" (G12b). "Yeah immediately. And solar cells system" (G12a).

Regarding inclusive energy transitions, our results provide contrasting impressions. Installers seem to slow down energy transitions by providing advice against retrofitting for budget-constrained customers. They advise these customers to buy new technologies in a later stage when prices are lower, e.g., "But if you see that a customer has a small budget. Then I advise them, in 2026 it is mandatory to buy a hybrid heat pump. But if you buy a gas boiler now <in 2024>, or at least schedule it for next year, then you have it <a heating installation> for €2.500,-. Then you have a very good boiler, lasting for fifteen years. And by that time, we will see what the prices are. As the prices for heat pumps in the Netherlands are, uh, in Spain you get them for half of the <Dutch> price" (R27). But our results from Rotterdam also show examples of installers' strategies to realise more inclusive energy transitions. For instance, a large installer has developed a collective hybrid heat pump that is placed on top of apartment buildings. This new installation is connected through the collective chimney to individual homes of the tenants and is more affordable than individual heat pumps. Another example refers to installer R27 who sometimes installs heat pumps against cost price to customers with limited budgets. The latter is regarded as unsustainable from an economic perspective. It may be done mainly by smaller installers as survival strategy in case they have limited projects rather than to support households. Both examples seem to be exceptions. It turns to be hard for installers to lower their price due to price competition and agreements with manufacturers. The major way to support customers to access expensive installations is by advising them to get subsidies and loans, which is difficult for installers as this requires more soft skills (cf. Section 4.3).

4.1.2. Upstream actors

Installers have power against upstream actors due to installers' access to end-users. Illustrative examples are energy utility ER2b who uses installers to scale heating transformations, and IoT suppliers R19 and R35 depend on installers to sell smart maintenance devices. The dependency is further evidenced by manufacturers that open 'brand experience centres' to demonstrate their products to end-users, but these manufacturers remain dependent on the installers' quality and time.

However, our results also suggest impact of upstream actors, having various effects on energy transitions. Firstly, installers face a manufacturers' lock-in as manufacturers provide warranty only on original spare parts. Moreover, the high complexity and heterogeneity of installations limits the possibility of installers to master multiple brands. This lock-in safeguards the quality of installations but may also negatively affect energy transitions as it reduces installers' options to combine modules from various manufacturers, as put forward by installer R9: "So, there <a modular strategy> is a solution to make things much easier. Manufacturers should help with that by standardising installations. For instance, that the cold-water connection is always on the right site and hot-water left. Now, it depends on which brand you work with". Such a strategy speeds up installation processes by working with more standardised modules. Moreover, manufacturers tend to be single product-oriented and do not sufficiently interact with manufacturers of complementing technologies (e.g., solar panels and heat pumps are 'separated' worlds, IF11) and products for the building envelope.

Secondly, upstream actors advise and train installers. This takes place through courses and physical demonstrations at manufacturers' and wholesalers' sites, at fairs, and online webinars. Manufacturers provide product training, but sometimes also courses on sustainability strategies. For example, a Swedish manufacturer trains installers on energy-efficient district heating pipes installation and integrating circularity. Wholesalers complement the training provided by manufacturers as wholesalers host courses on how to connect different technologies and their functioning in larger technology levels. Moreover, wholesalers provide advice on material use and project design, e.g.: "the counter of wholesalers is actually an educational institute for small installers" (ER4a). However, upstream actors may lack installers' craftmanship and contextual knowledge of projects (e.g., what existing installations look like). To compensate, wholesalers attract installers as staff, thus further increasing the shortage of installers.

4.2. Institutions

4.2.1. Certification

In both cases, certification is often voluntary, and control lacks. Consequently 'cowboys', who lack skills or willingness to deliver high quality, can enter the market. These cowboys represent a concern for installation quality and the good reputation of installers. So, interviewees indicated the need for stricter certification to increase the quality, although this also has negative effects. For example, mandatory certification for gas boiler installers was introduced in the Netherlands in 2023 – much later than in most other European countries[3] – and has increased the costs for certification and training. Some installers leave the industry thus further aggravating the labour shortage.

Installers and other actors also take action to build and maintain trust, and reduce the negative reputational effects caused by cowboys. For instance, associations provide information campaigns on the risks of installation mistakes (e.g., wrongly installed PV installations that may create fire) and advise households to work with certified installers. Also, digital platform provider R36, who connects installers with households, mainly works with certified installers and removes installers from its databank after negative reviews. Finally, installers themselves protect their reputation by post-installation inspections; correcting their mistakes; and by correcting each other. This latter is particularly relevant when installers outsource tasks to each other. To reduce the risk of cowboys in such practices, installers attempt as much as possible to work with reliable installers, e.g.: "Sometimes, we have a new installer we talk with. When the quality and price are OK, we add them to our network. But, when it turns out to be a cowboy, then it is really only once <that they work for us>" (R31). Taken together, creating and maintaining trust is essential in relationships between installers and customers and among installers.

4.2.2. Policies and regulations

Policies and regulations have various effects on installers. First, the speed of transitions caused by climate goals puts pressure on installers. This pressure further increases the shortage of installers, reduces their motivation and time for learning, and reduces time spent on providing proper advice. As put forward by installer R23: "so, you need to get well informed by installers on what you can do with it <a power amplifier>, but does the installer have time for that? And time is, of course, very limited at this moment".

Second, uncertainties in technology paths and inconsistencies in regulations postpone investments by customers, making it harder for installers to invest in new technologies and plan their activities. This was particularly the case in Rotterdam linked to natural gas phase-out ambitions where the national strategy was initially (in 2022) to set hybrid heat pumps as new standard to replace gas boilers from 2026 onwards. However, in 2023, an exception was made for monuments and apartments where heat pump installation turns out to be a challenge due to the large size of heat pumps compared to gas boilers. Such inconsistencies directly slow down transitions. For instance, social housing corporations mainly have apartments in their building stock, and accordingly, can still use gas boilers. It also indirectly affects transitions, as installers reduce efforts in innovations (e.g., the earlier mentioned collective hybrid heat pump) and capacity building (i.e., to master heat pump technology).

Third, public actors can 'oblige' installers to use digital platforms to increase the quality of installers. For instance, in Sweden, municipal housing corporations oblige installers to work with smart monitoring platforms. Such platforms offer installers an improved efficiency in their work, such as a faster response to interruptions in utility systems. However, compulsory digital tools also challenge installers. For example, heterogeneity of reporting platforms used by municipalities in the Netherlands, prevents installers from quickly scaling their business to other municipalities as they need to master different IT systems.

In Gothenburg the municipal utility and housing firms contract installers for installation, repair and maintenance services. This would, in principle, be beneficial to quickly achieve the climate goals: "the schools, you have the apartments where people live, and you have all these office buildings that are owned by the city of Gothenburg. … And those <municipal firms> have ambitions, like in 2030, they will triple their solar cells on all kinds of buildings" (G12b). However, a focus on the lowest purchasing price in municipal tenders rather than on energy saving limits options for on-the-job learning and quick goal achievement.

In Rotterdam, in contrast, the municipality has an indirect role but can set more conditions to support installers. The municipality explicitly perceives the energy transition as a chance for job creation for long-term unemployed persons and migrants. To facilitate (re)training of citizens to become installers, the municipality funds new installer training firms or on-the-job training in energy transition projects. Within these projects, the municipality imposes conditions on cooperation with vocational schools and unemployment agencies. Nevertheless, these measures mainly target start-ups or specific projects. In both cases, local authorities have challenges to reach the large group of small incumbent installers.

4.3. Skills

All interview partners stressed the shortage of skilled installers as the largest challenge for installers and energy transitions. Due to the specific learning modes, the variety in skill types and limited training infrastructures it is hard to reduce this shortage.

4.3.1. Learning mode

Nearly all interview partners referred to 'craftsmanship' as key skill for installers that they obtain through on-the-job learning-by-doing and informal learning from peers and supervisors. This is a long learning journey, e.g.: "a good installer needs a lot of experience. It is also about problem-solving. For instance, floor heating may function on the ground floor, but not on higher floor levels. This can be caused by an error in the installation or in the pipes" (IF8). The quote unveils a differentiation in skill levels, linked to the tasks that installers fulfil: installation, tuning, maintenance and repair. Hereby, 'repair work' requires more training than the other less advanced tasks. An implication of this differentiation is that placing new installations is done relatively quickly, however tuning – integrating a device within a larger system – requires more experience. Tuning is essential to increase energy efficiency but is not

[3] We are very grateful for an anonymous reviewer pointing us to this detail.

always done properly due to the lack of installers' training time and skills.

Another challenge is heterogeneity within installers' craftmanship. This makes it hard to quickly shift from one technology to another, or to attract installers specialised in another technology. The difference in craftmanship can be exemplified by the phase-out of natural gas heating installations. Installing electric heat pumps requires more time and specialised electrician skills compared to gas boilers which rely on mechanical engineering skills. This is due to the highly complex tuning processes and heat-loss calculations. However, unlike the annual gas boiler maintenance, heat pump inspections are simpler and occur every eighteen months. This illustrates the need for other skills and business models for Dutch heating installers who traditionally focus on maintenance services.

4.3.2. Type

Interviewees stressed that installers are product- rather than customer-oriented and lack sufficient communication skills to provide proper advice. Particularly smaller installers perform many tasks, of which communication is not their preferred one. The challenge of soft skills is even larger when installers need to communicate about new technologies as put forward by a Dutch gas boiler installer on an electric heating device: "But putting it on paper and getting it to the customer is what I find most difficult … I really have to make it clear in my mind that I will include it in my quotation next time: This system is intended for heating, not for cooling" (R27). Additionally, installers are increasingly challenged to provide building envelope advice. Traditionally, heating and insulation are separated worlds, and heating installers lack the skills of insulation installers (and vice versa). This may lead to challenges that slow down energy transitions, like 'tensions' between the installation of a single technology and the envelope: "the severe problem is that if you are a PV seller, you don't care much about the house, and perhaps it's the wrong investment for the customer" (G15). Beyond such sales-oriented cowboys, installers could also unintentionally make installation mistakes, especially when they work with relatively new installation types and need to provide holistic retrofitting advice.

4.3.3. Training infrastructure

Three interrelated challenges with formal education at vocational schools hinder energy transitions. Firstly, market demand, regulatory changes and technological developments increasingly require integration of traditionally separated utility fields to realise net-zero houses, but such integration is not yet covered by courses. Secondly, vocational training on understanding the functioning of single installations within the building envelop to save energy is still under development. Finally, schools still work with relatively old installations, despite manufacturers' eagerness to donate their latest installations for training.

4.4. Technology

The installation industry in general – and with major exceptions – is relatively conservative in adopting and deploying innovations. They often compete on price, have limited resources, and need to deliver a secure heating and electricity supply at low cost. They typically invest in new technologies mainly following market or regulatory changes. As illustrated by trainer G15: "How do we get the right product <new, more efficient installations> to the homeowners through this conservative installation installer branch?" Our results also show other nuances linked to the technology dimension.

4.4.1. Technology levels

Firstly, installers are confronted with a rapid development of new single technologies. This encompasses new technologies linked to transitions, such as heat pumps, and new versions of installations driven by manufacturers. Moreover, installers are challenged when selling more expensive energy-efficient installations as often installations need to be functional and low-cost, as evidenced by phrasings like "non-sexy products" (IF6) and "customers not knowing the brand" (R17).

Secondly, installers are confronted with technological integration challenges when connecting single technologies with larger systems and the building envelope: "Heat pumps, we know in Sweden. We know about the thermals. But then you mix them. And hybrid systems. How does it work? … And then you have to think about ventilation or how does it affect the ventilation system in the house" (G9a). Another example is a more complex tuning process of connecting a heating installation to floor heating systems rather than to radiators. Such technological integration challenges impede energy transitions due to installers' learning journeys and risk of making mistakes.

4.4.2. Digitalisation

Installers are increasingly challenged to work as IT specialists since governments require them to use digital tools (cf. Section 4.2) and manufacturers push smart systems with frequent updates: "Mainly digital things, I would say. So that is where it goes faster and faster. So, yeah, definitely a challenge for many installers" (G13). Digital integration of technologies in one system further increases complexity for installers. Even though application programming interfaces (APIs) to connect various brands of the same product develop rapidly due to mandatory industrial standards, different products in smart homes (e.g., heat pumps and solar panels) have different APIs and do not (yet) interact with each other. Furthermore, installers are challenged to connect smart products with relatively 'dumb' systems, such as district heating pipes that mainly detect leakages and do not measure energy efficiency.

Apart from these installation challenges, also other installers' services are challenged, including repair and maintenance, as different connected products may have different lifetimes and maintenance cycles. Likewise, installers have difficulties to monetarise predictive maintenance or provide holistic advice enabled by digital technologies: "Well, then you need to be able to sell value rather than hours. And that might be our greatest challenge, because we charge a customer for hours" (G16). Likewise, utility flows are measured in different data, making it harder for installers to provide holistic energy saving advise linked to these different flows. Finally, adding software to installations may lead to new disturbances and other types of problem-solving, such as customers' problems with apps to control heat pumps, or interrupted Wi-Fi connections that hinder PV monitoring systems.

4.4.3. Other

Installers and wholesalers increasingly start modular production and prefabbing. That means they work with standard modules, that they already partly connect with each other at the installers' rather than at the customers' site. For instance, 80 % of a collective hybrid heat pump is assembled at the installers' site. Installers use this strategy to speed up installation processes (e.g., G19, indicated saving 1/3 of the welding time by prefabbing), to reduce emissions at construction sites, and to include less experienced workers who can easily follow the manuals of the modules whereas experienced colleagues can spend more time on advanced installation work. Large and small installers increasingly deploy this strategy. For instance, large installer R21 has its own 'installation factory' to produce installation modules on a large scale, whereas a small installer has developed a modular frame where 'all' separate heat pump elements are pre-installed at its workshop and at the customers site this frame is connected to the heating system (R37). Other installers use this strategy indirectly by ordering pre-assembled installations from wholesalers, providing logistical advantages for installers. Overall, it is a strategy to increase efficiency and to reduce the labour shortage.

A nuance to this strategy is that manufacturers may block this strategy by not providing product warranty, or spare parts do not function when installers combine modules from different manufacturers. Moreover, this strategy seems to work well for new construction but is more complex for retrofitting where: “it is often only a part of the installation that you adjust. In case of large-scale renovation, then you could pre-fabricate things. But if you adapt only a part, then it concerns inspection, measuring, assemblage and installing” (R31).

5. Debate

Installers prove to be central actors that can make or break energy transitions. They are directly responsible for installation quality and indirectly shape transitions via their influential role in advising customers on retrofitting measures, and installation usage. Unlike other intermediaries, installers have a unique position due to their long-term mutually trust-based relationship with customers [7], deep craft-based skills, contextual knowledge [13], and involvement in post-technology deployment [41]. Our results confirm that installers are highly trusted advisors, whose customers follow their lead [16]. We also highlight that customers increasingly ask for holistic advice and the existence of ‘cowboys’ who challenge their respectable reputation. Installers and other actors reduce these negative effects since trust is key for them [30,50] and mistrust customer acquisition other than through personal referrals [26]. Mistrust hinders energy transitions, especially in the uncertain context of retrofitting markets [50]. Furthermore, we provide new nuances on the role of installers in inclusive energy transitions and wider just transitions literature [2]. Our results unveil that installers tend to advise low-income customers against retrofitting measures. As such, customers' budgets act as a transition barrier (cf. [8,13]). However, our findings also show some examples of installers attempting to include lower-income households. This is a topic to explore further, also considering how installers may act as intermediaries between social housing providers and low-income tenants, where the latter tend to be excluded in retrofitting decisions [59].

Regarding upstream relations, we confirm installers' influence on upstream actors due to installers' contextual knowledge on customers and buildings [13]. Conversely, manufacturers and wholesalers can also impact installers. In contrast to existing literature [42] on wholesalers as passive ‘distribution intermediaries’, our results show that upstream actors actively influence transitions by training and advising installers. As manufacturers may be oriented to their single product, this may lead to incomplete retrofitting advice. Additionally, a manufacturers' lock-in may safeguard installation quality but limits the options for quicker installation by applying modular solutions.

5.1. Challenges associated with institutional, technological and market dynamics

These challenges explain installation mistakes (Table 4) and provide further nuances on the changing roles of installers in energy transitions.

Table 4
Installation mistakes.

Installation mistake	Effects on energy transitions
Heating installations with too much capacity for the room size	Energy efficiency losses Higher purchasing costs
New heating installations in poorly insulated houses	Energy efficiency losses
Installers ignore or forget fine-tuning of installations	Energy efficiency losses
Installers ignore flue gasses regulations	Risk accidents
Installation mistakes with PV systems: wrong cables; open cables; wrong connectors; cables against sharp edges; too many PV panels for the capacity of the in-house fuse box; incorrect placement of roof tiles after PV installation	High repairing costs Risk accidents
Installations at places that are hard to reach for maintenance	Higher maintenance costs

We show that installers are the invisible Achilles' heel of energy transitions. The shortage of installers is a key barrier in energy transitions in Gothenburg and Rotterdam, with long on-the-job learning trajectories [28] preventing fast reduction of this shortage. Moreover, installers are challenged by the speed of the market, technological and regulatory dynamics of transitions [1]. Manufacturers quickly introduce new (digital) products, and the energy crisis has accelerated demand for energy retrofitting and holistic advice. Strict climate goals and inconsistencies in policies put further pressure on installers, increasing the risk of making mistakes and reducing time for learning. At the same time, the municipalities of Gothenburg and Rotterdam can hardly reach smaller installers (cf. [13]), while public tenders in Gothenburg focus on the lowest purchasing price rather than on energy efficiency goals linked to usage of installations. This limits installers' options to introduce new technologies and learn on the job. Accordingly, the need to change criteria in public tenders to realise energy efficiency illustrates the complexity of socio-technical transitions [33,60]. The latter is also evidenced by the slow development of certification and training systems in Sweden and the Netherlands.

5.2. Installers in transition: new roles and challenges

Due to the challenges installers face, we observe that they themselves are experiencing a transition beyond their traditional role as problem-solvers [30]. We have identified the following new roles of installers (see Fig. 2). The first is installers as *IT specialists*. We confirm that digitalisation in the installation industry is relatively slow when compared with other industries (e.g., banking) [14] and the downstream side of energy value chains [61]. Nevertheless, our data also unveil that installers increasingly work with digital tools as response to market, technological and institutional dynamics that ‘oblige’ installers to work with digital systems, affecting all installers' services (advising, installation, maintenance and repairing). Manufacturers introduce smart systems, and public customers require installers to work with digital platforms to safeguard installation quality and measure energy efficiency. However, this shift is complex as installers are confronted with various technological integration challenges and new business models (see Section 4.4).

A second role is that of installers as *manufacturers*. Large and small installers (and wholesalers) start prefabrication and modular production to reduce installation time [46]. They also deploy this strategy to manage the labour shortage by including workers in a safe ‘manufacturing hall environment’ that has less (or alternative) restrictions than a construction site or in peoples' home. Accordingly, highly experienced installers can focus on advanced installation work, and the installation industry becomes more inclusive for unexperienced workers from other industries or unemployed people [38]. Yet, challenges of this strategy are that it is mainly suitable for new construction and manufacturers' lock-ins reduce the options to quickly combine standard modules from different manufacturers. However, [59] mention that standard modules exclude low-income households in retrofitting decisions. Future research could explore the potential and challenges of ‘installers as manufacturers’, also considering the options to re-use standard modules and the transition towards the circular economy.

Whereas the shift towards the previous roles already takes place,[4] the last one is rather a desired role (depicted as a dotted line in Fig. 2) to enable retrofitting successfully (cf. [26,30]). Our data unveils that installers should change from specialised problem-solvers and advisors around a single technology to *holistic advisors* on how to achieve energy-efficiency by considering larger technological systems. As such, installers are not only an intermediary between upstream and downstream actors as stated in existing literature [16,21,28], but also horizontally

[4] We do not have numbers on how often these shifts take place, but our empirical data show that these shifts increasingly take place.

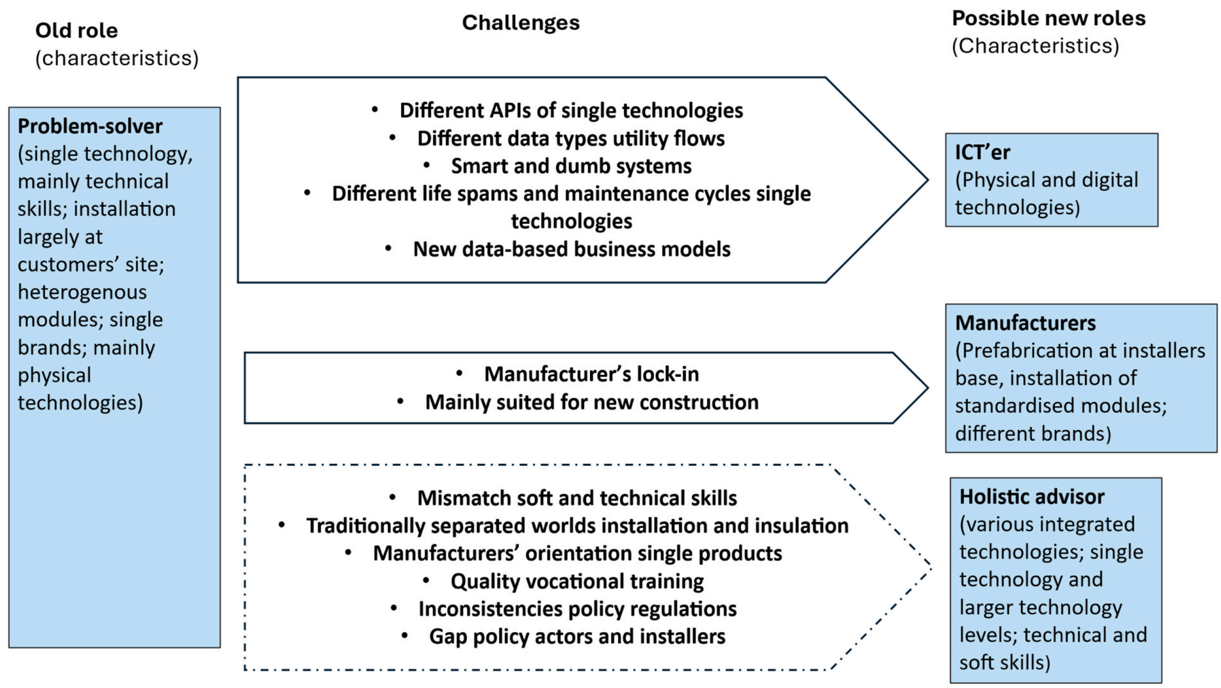

Fig. 2. Shifts in roles and challenges.

between the traditionally separated worlds of the installation and insulation industries. Thus, installers may play a role in the breadth of transitions [1]. We unveil challenges related to this desired shift, including a further mismatch between installers' craftmanship and soft skills [28] restricting installers in offering holistic recommendations. This challenge is even larger, and in line with other studies, we observe a gap between policymakers and installers [13] and inconsistencies in governmental regulations [8,27], both negatively affecting installers abilities to provide advice. Other challenges hindering this transition include manufacturers' orientation on single products, and vocational training infrastructure which lags behind the growing societal need for holistic advice [29].

Beyond the specific barriers for each new role, we have unveiled the conservative character of the installers industry (cf. [30]) as a generic challenge to realise all these shifts and energy transitions in general. This reluctance to change is explained by the fear of making mistakes that can lower the reputation of installers whereas the characteristic of their products as a basic need and price competition further limits their options to innovate.

5.3. Policy recommendations

To support installers in making, rather than breaking, energy transitions, we recommend that governments use other criteria than only the lowest purchasing price in their tenders. These criteria should encompass a focus on energy efficiency and provide space for installers on-the-job training and involvement in research programmes. Governments may also facilitate learning networks [50] among installers and other actors in their ecosystem. These learning networks should focus on joint learning and adaptation of educational systems enabling installers to obtain a holistic (or system) perspective. Finally, we suggest policymakers to cooperate with wholesalers to reach small installers. This is a key place to inform installers about new subsidies and regulations and obtain insights into challenges installers face. This is particularly relevant for the shift of installers and wholesalers to cope with the manufacturers' lock-in, while still enabling manufacturers to provide product warranty and compete on quality.

6. Conclusions

This paper contributes to the energy literature by focussing on installers, an incumbent actor that still has received limited attention among researchers and policymakers [8,13,16]. Whereas existing installers' literature is conceptual [21] or tends to focus on downstream relations, policies and energy retrofitting programmes [16,25], we take a broader ecosystem perspective. We apply this ecosystem perspective in two European cities: Gothenburg and Rotterdam.

We firstly argue that installers play a key role in making or breaking energy transitions. They directly affect energy transitions by the quality of their work and indirectly as intermediary who advise customers on technology deployment and usage. We unveil new nuances regarding downstream (installers sometimes deploy strategies to include budget-constrained users in energy transitions) and upstream actors (installers can influence manufacturers, but also face manufacturers' lock-in and are trained and advised by wholesalers and manufacturers). Secondly, we show challenges installers face caused by regulatory, market and technological dynamics of transitions, and identify new roles of installers as *IT-specialists, manufacturers* and *holistic advisors*, with the latter being a desired role. Finally, we show challenges installers face in transitioning into these new roles (see Fig. 2), and generic challenges hindering energy transitions, including a labour shortage and a conservative character of installers.

This is a qualitative study of only two European cities, so the results cannot be generalised. We propose more case studies in other cities and quantitative studies to further elucidate the role and challenges of installers in energy transitions. We also suggest a longitudinal study to obtain insights into the evolution of the new roles of installers, given the heterogeneity of installers and their interactions with other actors challenged to provide holistic energy saving advice and the struggle with the triple transition towards a digital, green, and inclusive future. More research on the role of installers in addressing energy inequality and insights into reducing the gap between policymakers and installers to achieve such complex transitions is also imperative.

CRediT authorship contribution statement

Erwin van Tuijl: Writing – review & editing, Writing – original draft, Validation, Project administration, Methodology, Investigation, Funding acquisition, Formal analysis, Data curation, Conceptualization. **Martin de Jong:** Writing – review & editing, Supervision, Funding acquisition. **Peter Knorringa:** Writing – review & editing, Supervision, Funding acquisition. **Emma Björner:** Data curation. **Sara Brorström:** Supervision, Funding acquisition.

Funding

This work was funded by the Erasmus University Rotterdam through the Erasmus Initiatives on 'Vital Cities and Citizens' (VCC) and 'Dynamics of Inclusive Prosperity' (DoIP), the International Centre for Frugal Innovation (ICFI) and the International Institute of Social Studies (ISS).

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Acknowledgements

We would like to thank Lucy Blyth and Eva Ferket for their support with the fieldwork. We are also very grateful to Luís Carvalho and Roman Martin who provided detailed and useful suggestions to improve the paper. Last, but certainly not least, we would like to thank the three anonymous reviewers and the editor for their constructive and extremely detailed feedback helping us to advance the paper considerably. The usual disclaimers apply.

Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.erss.2025.104290.

Data availability

The data that has been used is confidential.

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