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A Relational Approach to Understanding Inhabitants' Engagement with Photovoltaic (PV) Technology in Homes

Photovoltaic (PV) systems have been promoted in the UK housing sector as a key strategy for meeting carbon reduction commitments by offsetting the use of the non-renewable grid energy with renewable energy. However, inhabitants are not changing their routine energy consumption practices to take advantage of off-grid day time solar energy and, in some cases, even shifting practices away from the initial intentions underlying the technology. This means that necessary energy savings from new housing are not being achieved. In this paper, this is attributed to the variation in the provisioning of PV technology in new homes, as well as inhabitants' engagement with and know-how of PV technologies, subject to explicit rules and polices. The key contribution of this paper is to reveal how PV technologies and inhabitants interact within different socio-technological home contexts drawing on Practice theory and ethnographic methods applied to four cases within a case studyof housing development in England.

Key words: community housing, Photovoltaic (PV), practice, inhabitants, socio-technological, energy performance gap

1. Introduction

Mitigating carbon emissions (CO_2) reduction is an absolutely a critical international challenge following the announcement of an increasing likelihood of global warming above 1.5ºC from pre-industrial levels, thus increasing the global risk of severe drought, floods, storms and extreme heat (IPCC 2018). Reducing greenhouse gas (GHG) emissions is particularly significant in the building sector as it accounts for approximately 40% of the global (GHG) emissions (UNEP 2017) and 19% of the UK (GHG) emissions (CCC 2018).

New policies, incentives and technological innovation have been developed to deliver low-energy homes in the UK (Schelly 2016), where housing is currently responsible for 77% of the total direct CO_2 emissions from the building sector (CCC 2018), and 14.5% of the total CO_2

emissions in the UK (Committee on Climate Change 2019). The ground-breaking Code for Sustainable Homes (CSH)[1] (launched in 2007) and Feed in Tariff (FIT)[2] (launched in 2010), encouraged the rapid installation of domestic Photovoltaic (PV) systems in the UK (DBEIS 2017), which represent the largest cumulative installed capacity confirmed on FITs by the end of 2018 (DBEIS 2018). (Figure 1)

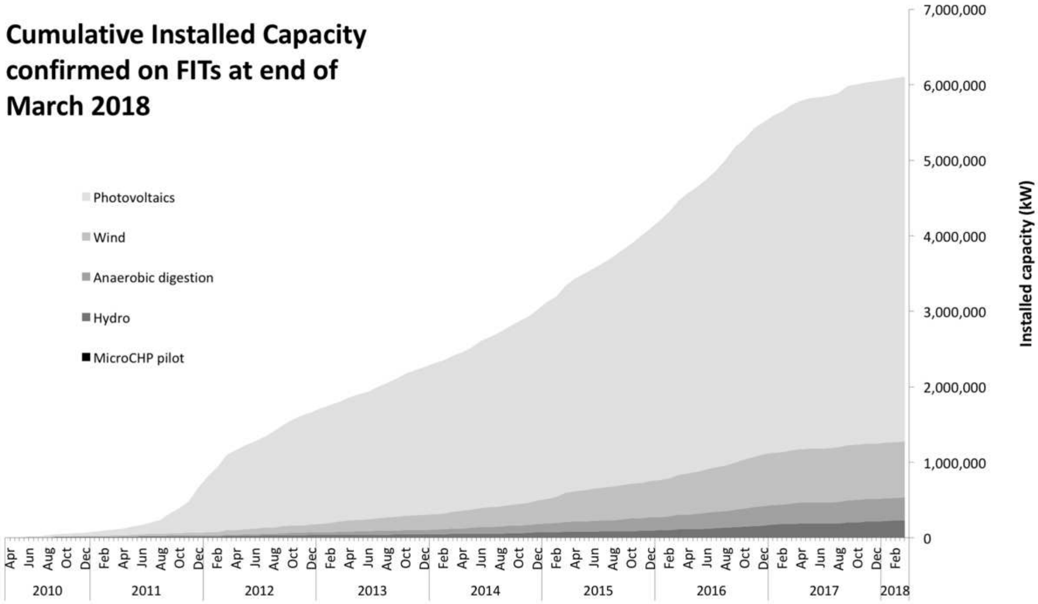

Figure 1. PV installations in the UK compared to other microgeneration technologies (DBEIS, 2018)

The FIT policy aim was to offset the use of the non-renewable grid energy with renewable energy, and thus reduce the CO_2 emissions right across the UK in order to meet the government low carbon plan of reducing CO2 emissions by 80% against 1990 levels. (DBEIS 2018). PV installations also increased worldwide from 9.2 GW in 2007 to 404.5 GW by the end of 2017,

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[1] CSH Code levels 3 and 4 required the equivalent of a 25% and 44% CO_2 emissions reduction respectively in relation to the Dwelling Emission Rate (DER), leading to the ‘zero carbon’ standards (code levels 5 and 6).

[2] The UK’s FIT consists of two payments made by the energy supplier to the registered PV installations during the eligibility period of 20-25 years: generation and export tariffs. See (Energy Saving Trust 2014) for more details.

and represents the largest power generation technology added in 2017 (SolarPower Europe 2018) (Figure 2).

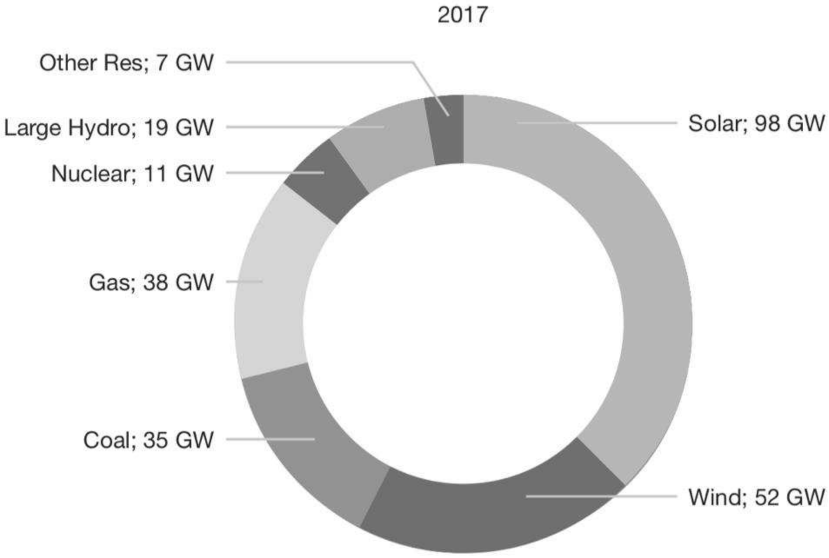


Figure 2. Net power generating capacity added in 2017 (SolarPower Europe, 2018)

However, the theoretical assumptions behind these polices and technological paradigmwere unrealistic as new homes routinely uses up to three times the amount of energy that was predicted to be used during occupancy, resulting in a persistent ‘energy performance gap’ between design intentions and reality (Boyd and Schweber 2018). This is largely attributed to the general assumption that building use is independent of building energy efficiency, with a large emphasis placed on the physical and technical properties of new technologies compared to social aspects of inhabitants governing their energy efficiency in new homes, as a result (Galvin 2014). In reality, inhabitants do not change their routine energy consumption practices to take advantage of renewable solar energy, resulting in a large proportion of their PV energy still being exported to the main grid rather than used directly, particularly during high PV generation periods in the daytime (Baborska-Narozny, Stevenson, and Frances 2016). This can have a negative impact on the grid stability in terms of the voltage quality of the UK residential low voltage distribution network (Bottaccioli et al. 2018).

Policies and new technologies therefore need to consider the actual use of PV technologies by inhabitants if a real reduction in domestic energy consumption is to be achieved to combat climate change (Visscher et al. 2016). The main aim of this paper is to shift the focus from technical features of energy use to consider the entanglement of PV technologies and polices within inhabitants' everyday practices in homes using a Socio-technological approach (Tweed 2013).

Previous studies have examined the role of building actors in shaping inhabitants' engagement with their domestic technologies (Gram-Hanssen et al. 2017, Wade, Murtagh, and Hitchings 2018, Frances and Stevenson 2018), and the role of the fragmented contractual arrangements and planning requirements in omitting the PV systems from the main design during the construction process (Boyd and Schweber 2018). Other studies have focused on the impact of the PV system in changing inhabitants' energy consumption practices (Haas et al. 1999, Keirstead 2007); the possible ways that inhabitants can improve their use of PV energy (Luthander et al. 2015, Jenny, López, and Mosler 2006), and in relation to the introduction/ change of PV policies and incentives (Wittenberg, Blobaum, and Matthies 2018, Baborska-Narozny, Stevenson, and Frances 2016). However, there is virtually no detailed coverage in the literature of inhabitants interacting with their PV systems. This paper therefore examines how inhabitants actually engage with their PV system in different socio-technological home contexts, and in relation to their overall energy consumption practices using Practice theory. This theory overcomes the limitations of regulated low carbon housing policies, standards and new technologies by providing a way to understand the co-evolving of human actions and objects within real contexts when examining the energy performance gap in homes (Gram-Hanssen 2010, Killip 2013).

For the purpose of this paper, the definition of a PV system is one that consists of solar panels, an inverter, a meter, AC/DC isolating switches and a wiring system. The PV meter shows how much energy the system is generating, while the inverter shows the energy generation output instantly and over time (e.g. week, month, year) when inhabitants actively log into these data (Mohanty et al., 2013) (Figure 3).

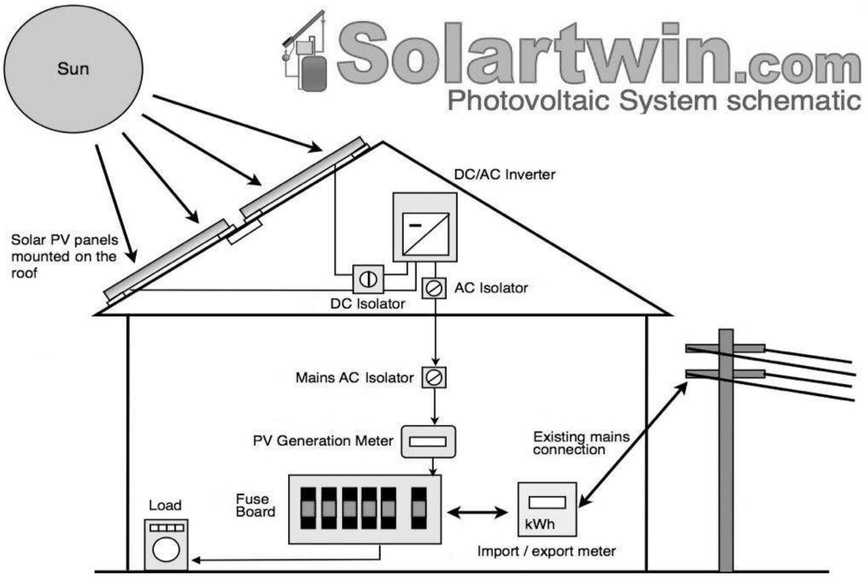


Figure 3. Solar PV components arrangements inside the house (solartwin.com)

In some cases, smart monitors also help inhabitants understand their energy generation and consumption patterns, and to actively manage their energy loads by matching their energy consumption with that generated in real time (Wind & Sun) (Figure 4).

Figure 4. Smart PV monitors (Wind & Sun)

The next section introduces Practice theory as used to examine inhabitants’ engagement with their PV systems. The following methods section introduces the four community housing developments within a case study based in England. The subsequent findings are then cross related to understand the differences in inhabitants' practices in these different socio-technological contexts. The conclusions section brings all these issues together.

2. Practice Theory

Practice theory is a 'temporally unfolding and spatially dispersed nexus of doings and sayings' and combines social order and individual's actions in specific practices (Schatzki 1996: 89). Practice ontology sees users as independent actors, where people get things done through their know-how and meanings, in association with rules as key elements when performing practices (Reckwitz 2002). Shove and colleagues, later on, re-group the elements holding these practices together and add the material entity as a central element that can prefigure practices in certain ways (Shove, Pantzar, and Watson 2012) instead of being only situated within a context of different practices (Schatzki approach). Various studies have found a clear difference in inhabitants' perception of comfort and their everyday heating practices as a result of the change in the material configuration and arrangement of heating houses (Hansen, Gram-Hanssen, and Knudsen 2018, Masden 2018). Inhabitants practices of their PV system, therefore, are examined in this paper within four key elements (Gram-Hanssen 2010):

(1) Technologies and products. This refers to the physical characteristics of the PV appliances and their integration into the homes.

(2) Know-how and embodied habits. This includes the skills and know-how that the practitioners have or acquire in in terms of how to carry our any practice.

(3) Institutional knowledge and explicit rules. This refers to the policies and regulations of the governments, written advice and any other technical knowledge and documents that influences the system design and use.

(4) Engagements. This refers to the symbolic meaning, social expectations, inspiration, purposes, and beliefs.

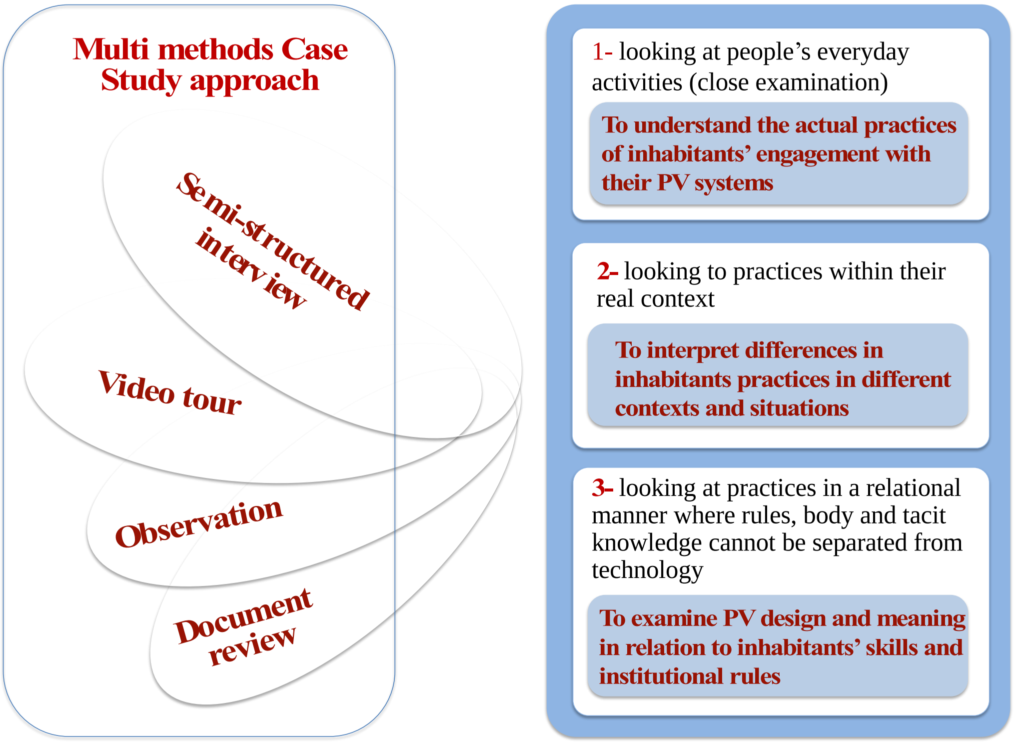
Understanding practices using Gram- Hanssen's four elements also helps to better identify and interrogate the role of national polices, standards and established technical knowledge as explicit rules, in shaping the PV inhabitants' practice independently from the role of implicit their practical know-how and embodied habits, which Shove combines under a competence element.

The relational thinking concept of practice theory (Shove, Pantzar, and Watson 2012), emphasises that none of the four elements should be understood in isolation from the others when examining PV practices (Nicolini 2011). This suggests that knowledge acquisition in practice is an activity rather than an object, where thought, body and tacit knowledge cannot be separated from technology (Ingold 2000). This means that different ways of knowing-in-practice can be presented when enacting PV practices (Nicolini, Gherardi, and Yanow 2011). This requires an examination of inhabitants' everyday PV and energy consumption practices in their different socio technological contexts, as discussed next.

3. Methods

Practice theory 'directs the researcher's attention to what people do and say, to the world of life made of the details and events that constitute the texture of everyday living' (Nicolini, Gherardi, and Yanow 2003: 28). Therefore, ethnography (a videoed home tour with direct observation) combined with semi-structured interviews provides themethods for understanding what people say and do in their everyday PV practices (Corradi, Gherardi, and Verzelloni 2008) (Figure 5). Ethnographic observation also helps to examine what the physical properties and arrangements of PV technologies afford their inhabitants in a context of practical actions (Zeisel 2016).

Finally, a document review was undertaken to further understand the rules involved in PV practices (see Figure 5).



1- looking at people's everyday activities (close examination)

To understand the actual practices of inhabitants' engagement with their PV systems

2- looking to practices within their real context

To interpret differences in inhabitants practices in different contexts and situations

3- looking at practices in a relational manner where rules, body and tacit knowledge cannot be separated from technology

To examine PV design and meaning in relation to inhabitants' skills and institutional rules

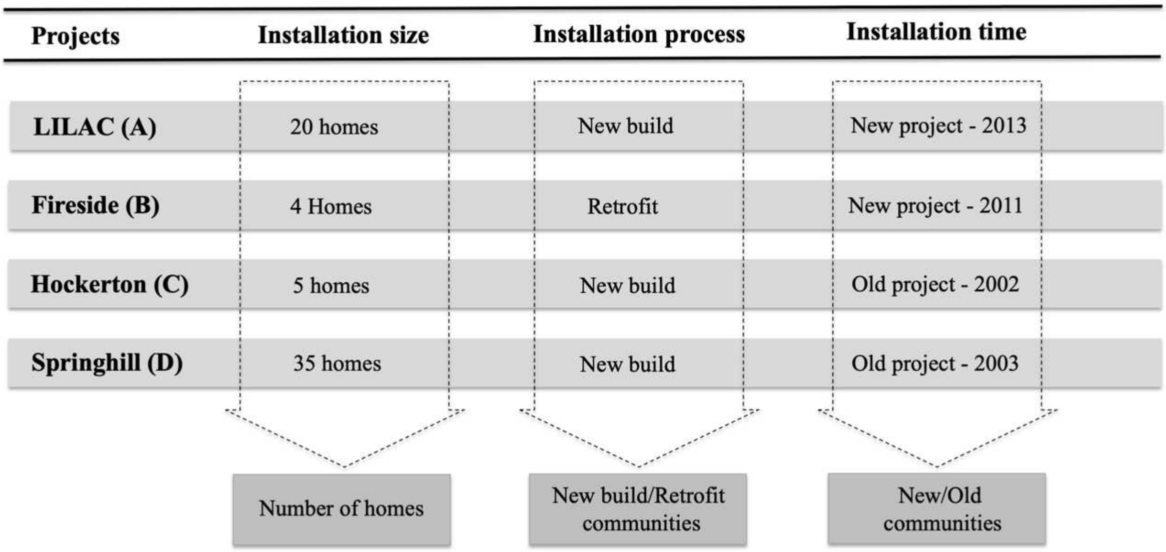
Figure 5. Four methods to contextually examine inhabitants' practices

A Case Study approach is adopted in this paper as 'an empirical inquiry that investigates a contemporary phenomenon within its real-life context' (Yin 2013: 13), which can intensively examine inhabitants' engagement with their own PV system in a greater detail as well as a multitude of variables and contexts (Schelly 2016).

The chosen 'exemplars' method for case study selection ensures the participation of a group (e.g. PV inhabitants) that are relevant to the research question and the theoretical proposition of this paper, thus increasing the generalisable quality of the research (Flyvbjerg 2006: 219).

Four ground-breaking and multiple award-winning low carbon housing cases were selected in this paper based on the criteria of exemplars of community housing projects within a defined area of England, rather than aiming to geographically represent the whole of the UK, (Chatterton 2015, Tummer and MacGregor 2019, Egan 2004, Pasquale, Gill, and Firth 2013). This is due to the differences in regionsbetween regulations and rules for housing and other sociocultural meanings of products and practices. The selection of four cases within a case studyshows replicated or contrasted situations between cases, thus, overcoming the vulnerability of depending on a single case (Yin 2013).

The cases deliberately included a variety of individual PV systems installed in terms of sizes of PV installation, installation dates and different processes, and with a focus on smaller housing developments in order to be able to understand inhabitant practices within more easily identifiable developer rules. (Figure 6). The cases selected were: LILAC (Leeds- completed 2013) (A), Fireside Co-operative (Sheffield-2011) (B), Hockerton Housing Project (Nottinghamshire-2002) (C) and Springhill (Stroud-2003) (D), all in the UK (Figure 7). One retrofit case was also deliberately included to tease out any issues related to this case and cross-relate them to the new –build cases.



Projects	Installation size	Installation process	Installation time
LILAC (A)	20 homes	New build	New project - 2013
Fireside (B)	4 Homes	Retrofit	New project - 2011
Hockerton (C)	5 homes	New build	Old project - 2002
Springhill (D)	35 homes	New build	Old project - 2003

Figure 6. Installation characteristics of the four PC case studies

LILAC Co-housing (A)

Fireside Co-operative (B)

Hockerton Co-housing (C)

Springhill Co-housing (D)

Figure 7. Case studies as built

After initially reviewing the PV documents provided to inhabitants during the home induction process (e.g. Home User Guide (HUG)) and site visits, the subsequent 14 semi-structured interviews with PV inhabitants across the four casea provides a broad understanding of inhabitants' claimed practices of PV technologies and how they situate themselves with these technologies as related to their overall energy consumption practices (Valentine 1997). The interview questions were classified into five main sections (Figure 8).

Interview questions with inhabitants

1- Inhabitants' PV and energy use discussions and networks during occupation

- What position do you hold in your community? Do you have any specific role? What is it?
- What is the role of your community now in developing your knowledge in relation to your interaction with your PV system or how to make the best benefit from it in your home?
- Were there any group discussions about PV interaction that highlighted problems?
- Are there any negative issues from living in a community housing in relation to your PV system?

2- PV practices

- Did you have any experience of using PV systems before you lived here?
- Did this affect your practice of interacting with your current PV system? How?
- Were you ever introduced to the PV system and how to use it before you moved into the home?
- Did this guidance have any influence on your interaction with your PV system or how to make the best benefit from the generated energy? How?
- How usable are your PV features in your home?
- What parts does your PV system have?
- Which part(s) of your PV system you have an interaction with in your home?
- Are you aware of the function of each part and how to interact with it?
- Has this interaction had any effect on your energy consumption?
- Did your interaction with your PV system meet your expectation in terms of practice/energy generation or others?
- Have you changed your way of using energy after the installation of your PV system in your home? How?
- Are there any unintended consequences from having a PV system in your home?

3- PV problems

- Are there any specific problems in your PV system or your daily interaction with any parts?
- Did these problems affect your interaction with the system? How?
- Did this problem affect the efficiency of the system's energy generation or how to make the best use of energy produced by the system?
- How did you deal with this problem?
- Were there any issues relating to the maintenance of your PV system?

4- PV changes

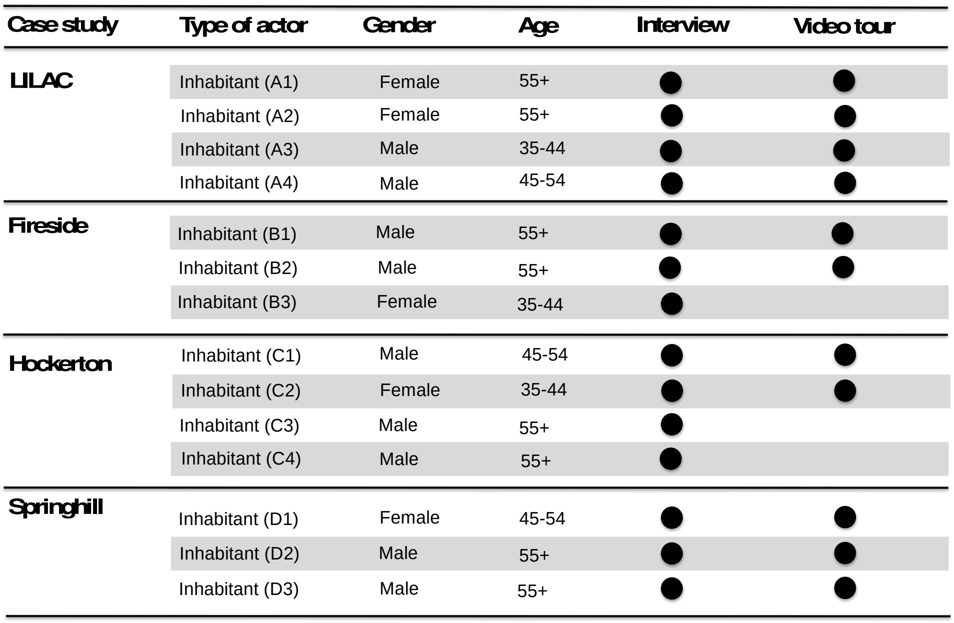
- Did you make any change in your PV system or how you interact with the system to increase the performance?
- Did this change enhance the efficiency of the system or your interaction?
- Have any changes been adopted by other people in your neighborhood?

5- Key recommendations

- What new features do you think are important to add to the system in your home to improve it or your interaction with it?
- What good practice 'interaction' in relation to the different part of your PV system should be used again? Why?

Figure 8: Interview question with inhabitants

An ethnographic home tour was conducted and videoed immediately after finishing each interview with each inhabitant (Pink 2009) (Figure 9).



Case study	Type of actor	Gender	Age	Interview	Video tour
LILAC	Inhabitant (A1)	Female	55+	●	●
	Inhabitant (A2)	Female	55+	●	●
	Inhabitant (A3)	Male	35-44	●	●
	Inhabitant (A4)	Male	45-54	●	●
Fireside	Inhabitant (B1)	Male	55+	●	●
	Inhabitant (B2)	Male	55+	●	●
	Inhabitant (B3)	Female	35-44	●	
Hockerton	Inhabitant (C1)	Male	45-54	●	●
	Inhabitant (C2)	Female	35-44	●	●
	Inhabitant (C3)	Male	55+	●	
	Inhabitant (C4)	Male	55+	●	
Springhill	Inhabitant (D1)	Female	45-54	●	●
	Inhabitant (D2)	Male	55+	●	●
	Inhabitant (D3)	Male	55+	●	●

Figure 9. The participated inhabitants in the four case studies

This was to further understand inhabitants' know-how and meanings by observing what and how they engage with their PV appliances in different socio technological home contexts. All the interviews and video tours were recorded and fully transcribed and ethical issues related to consent and confidentiality were addressed according to the ethical policy of The University of Sheffield

An abductive[3] approach for data analysis (Braun and Clarke 2006) was employed to identify themes within the data using a pre-coding manual and subsequent free-coding to exhaust the data, and to make sense of the empirical data in light of the four elements of Practice theory. The findings are discussed in the next section under four sub-sections with each one relating to each of the four practice elements. However, as the findings are interrelated in different

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[3] An abductive analysis is an iterative dialogue between the empirical data and existing theories in order to provide a more comprehensive understanding of a phenomenon, and to advance an existing theory based on empirical setting (Dubios and Gadde 2002).

ways, being equally important and influencing practices according to Practice theory, there are inevitability cross-over findings between these sections (Figure 10).

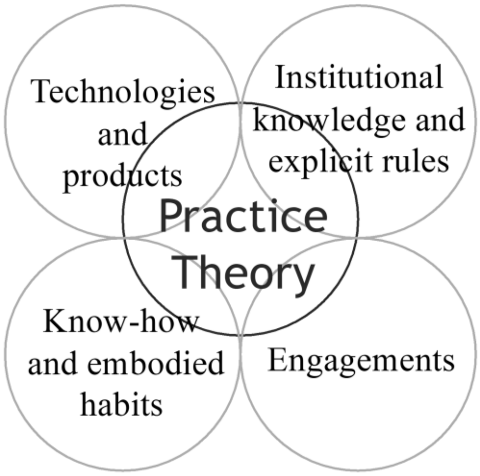

Figure 10. Interrelated practice elements for data analysis

4. Inhabitants Practice of their PV System

4.1 Practice via Technologies and products

Two key aspects in relation to the material configuration of PV systems and products are discussed in this section: technology design and arrangement.

4.1.1 Technology Design

Three key aspects critically influenced inhabitants' engagement with their own PV appliances and motivation to match their energy loads in order to reduce the imported energy from the grid.

- Feedback provision

The key PV design issue cited by inhabitants in all case studies during the videoed home tour was the limited provision of visual and direct feedback for PV energy generation and overall energy consumption in an individual home, instantly and synchronously (Figure 7).

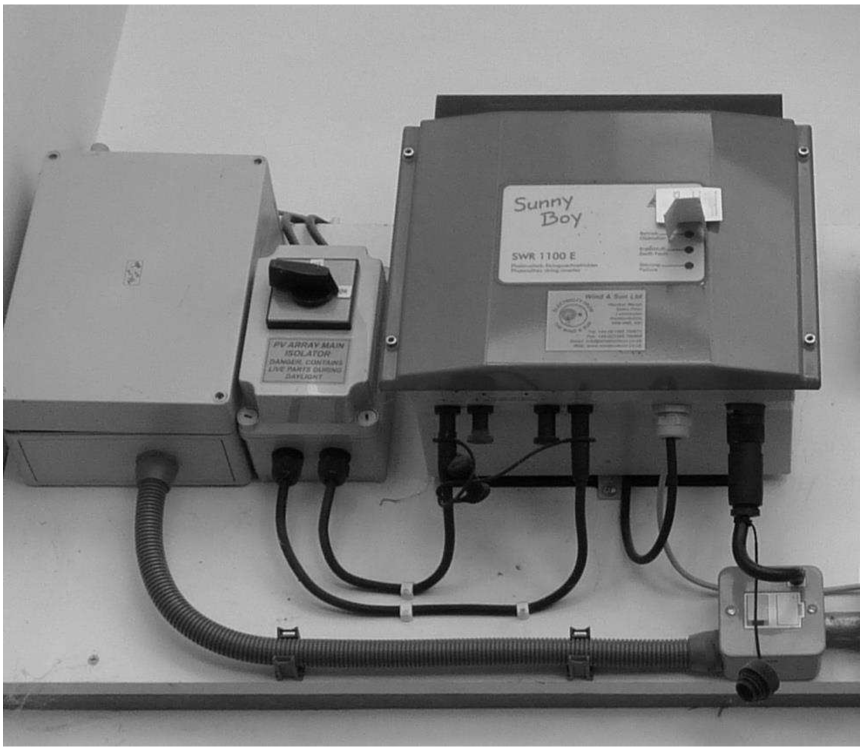

Figure 7. Poor provision of energy feedback in the installed inverter in case study C

Only in cases A and B, did the inverter have a display screen to show how much electricity the system was producing when inhabitants engaged with it. Tellingly, however, some inhabitants claimed that understanding PV generation patterns alone did not help them to match their energy loads individually to reduce the imported energy from the grid: '… It is messy now. I can tell you that the PV adds units all the time … it is just not practicable …' (A2).

This inhabitant wanted the energy generation data to be visually related to his own energy consumption practices for it to become useful. Other inhabitants suggested providing the PV meters and inverters with Wi-Fi capability to download the PV energy generation data during the day by inhabitants. This was unavailable in all four cases.

- Detailed design aspects

The detailed design of PV technology critically influenced both inhabitants' engagement with their own PV appliances and the functionality of the system. The poorly illuminated and small size display screen of PV generation meters and inverters in case studies A and B (Figure 8), for example, discouraged inhabitants from monitoring their energy generation regularly in order to match their energy loads. One inhabitant described a PV meter lighting problem very specifically:

> ‘Oh, I think there is a problem with the meter. It does not have a lighted screen; I need to shine a torch on it at a certain angle when I’m looking at the numbers. I think it is the same problem with anybody else.’ (A4)

Figure 8. Poor illuminated display screen in the PV meter

The PV panels in cases B and D were wired and connected in series. This meant that if: ‘… a panel/tile was in the shade (due to chimneys, clouds, trees) the whole system suffered at once and energy generation fell dramatically’ (D4). This inhabitant also suggested that adding ‘Micro inverters allows each panel to act independently’. Another PV design issue that influenced the functionality of the system concerned the instability of PV panels on the roof. The majority of inhabitants in case C pointed out that the PV panel support frames were not sufficiently weighted down on the roof by the installer. As a consequence, high winds resulted in some of the PV panels being blown onto the ground and damaged.

- Communal use of PV energy

A PV system is often understood by the policy makers and installers as an individual system for energy generation and consumption, rather than as a system that has the potential to be used communally to increase the benefits. One inhabitant claimed that the method used to connect the PV systems to the houses in his case (A) did not allow the energy generated from all the PV systems to be used communally by all the inhabitants. He suggested:

> 'Now, what would be far better is that, OK, when we are at home and everybody else is out at work, there is a technology which would allow us to use the electricity from everybody's panels, so we could, for example, boil an electric kettle, which we could not do purely with one pathetic solar panel '. (A2)

Enabling inhabitants to share their energy can significantly improve their energy consumption practices and reduce the energy imported from the main grid. An individualistic understanding of PV systems, by contrast, significantly undermines the development of local energy grid practices and the introduction of other strategies in the UK (Kok et al. 2012).

4.1.2 Technology Arrangement

The physical location and integration of PV appliances into homes can also prefigure inhabitants' engagements with their PV appliances and their subsequent energy consumption practices during occupancy. PV appliances, particularly the inverters and the panels, were often located by the installers in hidden locations for aesthetic considerations. In case B, for example, the installer located the inverter and meter in the cellar '… because we did not want to lose any useful space to these devices … and (it) is invisible' (B2). As a consequence, inhabitants were not aware of how much energy their PV system was generating in different conditions. They did not observe the display screen in their inverter frequently enough, in order to strictly match their energy loads and to achieve the potential energy saving as a result:

> 'Now, if I want to see how much our system is generating, I have to walk down to the cellar…I think if we had that in the kitchen, I would be more interested to look at it every day, or every hour, and then that would affect my energy usage behaviour. We are aware that quite a lot of our energy generation goes back to the grid. It is an issue.' (B3)

The question of where inhabitants spend the longest time in their house during the day (e.g. kitchen, lounge) is, therefore, important in terms of where and how the energy generation display screens and smart energy monitors should be integrated into the home. This is because this positioning prefigures the inhabitants' later engagement with the system appliances and energy consumption habit formation. Poor positioning of the inverter also took place in two other cases with the inverter located in a cupboard under the stairs (A), in the porch (C) and in the attic (C) - all hidden away (Figure 11).

Poor integration of PV panels into homes had negative impacts on effective PV performance and inhabitants' maintenance practices. In three cases (A, B, D), poor positioning prevented inhabitants from be able to clean their dirty PV panels, and to see whether the panels need cleaning or not due, to the panels being located in inaccessible and hidden places (Figure 9).

Figure 9. Inaccessible and hidden PV panels (A)

More significantly, this negatively affected the system performance in cases B, C and D due to locating the panels on the roof area overshaded by trees (C, D) or chimneys (B) (Figure 10). These are examples of how the decision on where to locate the PV panels and inverters by the installers can lead to excessive problems in relation to the system performance and inhabitants' engagement with the PV appliances.

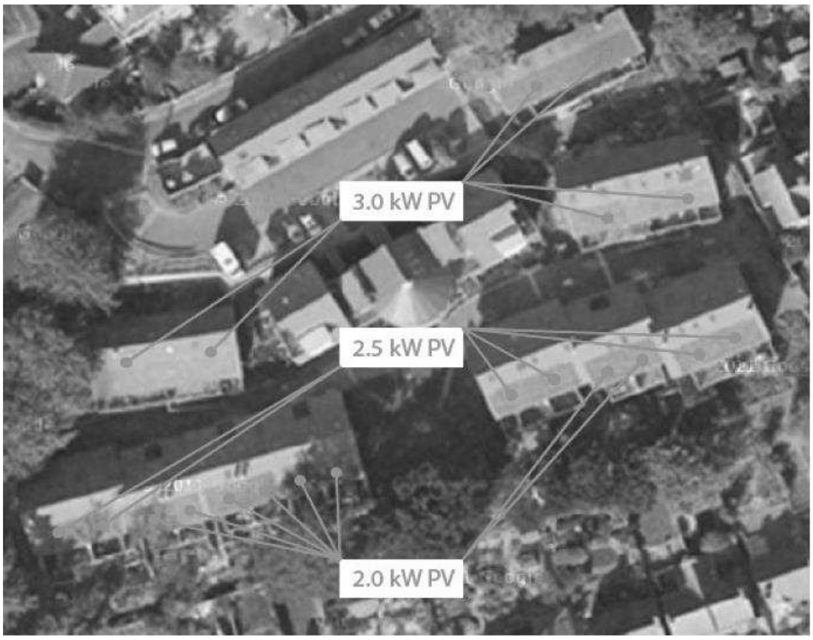

Figure 10. Trees shadows on PV panels (Pasquale, Gill, and Firth 2013)

Previous PV studies have examined the role of technical solutions and feedback technologies in improving energy consumption practices, but only on individual level (Hondo and Baba 2010, Luthander et al. 2015). The intensive empirical findings in this paper highlight the high potential of using these technologies on a community level by developing communal PV and energy management technologies and practices (e.g. community batteries, local energy grid systems).

4.2 Practice via Know-how and embodied habits

A large number of inhabitants in all cases were disengaged with the PV appliances due to a lack of know-how. The research video tours revealed that the Nominated Inhabitants (NI)[4] who participated in construction process of their own homes (A, B) were aware of how to engage with their inverter display screen. This helped them understand the performance of their PV system. Other community inhabitants commented that they did not know how to engage with them. This meant they did not considerably change their energy consumption practices to match energy useage with energy generation. Inhabitant A1 stated: '… I don't have to check it (author: the inverter) for anything. I don't know what is for or how to use it'. This was because the NIs did not transfer this know-how effectively to other community members – a vital omission. In case study C, the NI effectively transferred his know-how in relation to effective maintenance practices to other community members and this ensured regular cleaning of all the PV panels. All inhabitants in case study B knew how to read their PV meter for the FIT. However, only one inhabitant claimed to take to meter readings every week; the other inhabitants did not, for reasons that will be discussed in the next section.

The know-how of two inhabitants (A), who tried to strictly match their energy loads by observing their inverter display screen, was highly restricted by the poor location of the inverter in their homes, despite them trying to learn how to engage with it (Figure 11). This shows the

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[4] The inhabitants who have participated in the provisioning process of their homes with the other professionals.

significance of examining know how in relation to the other elements of Practice such as engagement and technology and products.

Figure 11. Poor location of the inverter (A)

A previous study has claimed that inhabitants' governance of their PV system can improve their know-how of using the system and stimulate energy consumption behavioural changes (Dobbyn and Thomas 2005). This paper shows that this is not always happening in community housing projects. This is due to these skills being confined to the NI, and not transferred effectively to the other community members – a significant omission. The intensive empirical findings here also show in detail how know-how can be highly undermined by the physical contexts of the PV system.

4.3 Practice via institutional knowledge and explicit rules

The institutional rules governing the FIT process was the key positive policy influence in terms of inhabitant's greater engagement with their PV meters in all the cases, with rules stating that inhabitants had to send their meter reading every three months to their energy supplier company in order to claim the financial payback from their system. This was substantiated by one inhabitant who said they they were ‘Taking meter reading when the main electricity supplier (EDF) ask me to do that for the FIT’ (D1). By contrast, the high payment rate of the FIT stopped two inhabitants (D) from managing their energy loads appropriately:

> ‘The issue of whether we use energy during the day or not was not so important because the attraction was the FIT. The FIT was very high.’ (F4)

Inhabitants in case D stated that they had stopped recording their energy generation and consumption readings and producing energy graphs collectively, after the completion of their contract with the grant body ended the institutional rule requiring monitoring, despite all the monitoring equipment remaining in place after the contract had ended. This resulted in all inhabitants becoming less literate about their energy generation and consumption patterns, which had helped them to:

> ‘…identify some underperformance problems very quickly’ (D3); ‘change some energy consumption practice by using energy more during the day such as having showers during the day, changing the light bulbs to the economy one’ (D2).

By contrast, all inhabitants interviewed in case C stated that they had continued monitoring their PV systems collectively, despite the completion of the contractual rule requirement with the grant bodies. Institutional rules, therefore, cannot be relied on alone to ensure the sustainability of a PV practice and energy consumption reduction over time as a habit; other elements such as active meanings and goals (see 4.4.1), also need to be sustained and developed continuously to sustain engagement.

Two further explicit rules that influenced inhabitant engagement with their own PV systems were: community and technical knowledge rules. A large number of inhabitants in case B, did not observe their PV meter and inverter display screen due to a community member monitoring all the PV system as a community rule. This consequently reduced inhabitants' motivation to strictly match their energy loads. Similarly, some inhabitants in cases A and B disengaged from learning about the different aspects about their PV operation and practice due to specific communal arrangements as rules. One inhabitant ascribed her own low motivation to learning as being due to:

> … other people using the same system, I do not have to worry about it because I have always got somebody I can go and ask … I suppose if I was in my own home or just had one neighbour, I have to find out and understand everything about my system. I'm a bit lazy now (A4)

However, the videoed home tour revealed that she had no idea about how to engage with her own inverter's display screen, which meant that she was illiterate about her PV energy generation periods. This knowledge could have encouraged her to change some energy consumption practices to reduce the imported non-renewable energy from the grid such as 'having showers during the day … using the communal washing machine' as practised by inhabitant' (D2).

Lack of appropriate technical knowledge as rules provided to inhabitants via PV documents (e.g. Home User Guide (HUG)), led to some inhabitants to cover their inverter with clothing (Figures 12). This was due to their limited awareness of the significance of keeping the inverter well ventilated and cool to increase the performance of the PV system. Lack of documents setting out explicit rules also led some inhabitants (D) to not clean their inaccessible PV panels by using a pressure washer, despite the dramatic reduction in their energy generation due to dirt on the panels. This was due to developing an informal rule based on the inhabitants' perception of cultural norms, perceiving glass material as something fragile and not to be power-washed.

Figure 12. Inhabitants covering their inverters with clothes

This section also shows the role of specific arrangements of a community housing group as an explicit rule in hindering inhabitants from individually monitoring their PV systems and increasing their energy performance literacy, , something unidentified in previous studies in this area (Baborska-Narozny, Stevenson, and Frances 2016, Keirstead 2007, Wittenberg and Matthies 2018).

4.4 Practice via Engagements

4.4.1 Active Meaning vs Passive Meaning

Two key meanings were attached to PV systems by inhabitants in the selected cases. One group of inhabitants perceived their PV systems as a passive technology that only generates green and free energy (cases A and D) and required very limited engagement from them. By contrast, a second group (mainly in cases B and C) understood their PV systems as an active technology that had the potential to impact on their energy consumption practices. Accordingly, active inhabitants routinely and collectively monitored their energy generation and consumption patterns in order to actively manage their energy demand by changing their energy consumption practices. This also led some inhabitants to further reduce their overall energy consumption and cost, by matching their energy consumption with what had been generated from the PV system. As one inhabitant stated:

> 'It certainly made me aware of a potential for low energy consumption. It made me aware of how many little things we use, we adapted quite a lot, and then the solar would actually cover the use of a lot of those.' (B1)

The passive inhabitants did not engage with their PV appliances, apart from taking PV meter readings every three months for the FIT. They wanted, instead, to add a technology battery to their system, in order to be able to use their PV energy at any time without changing their energy consumption practices. This means that they were not trying to reduce their overall energy consumption in order to match their PV energy generation.

4.4.2 Meaning Transformation

The best transformation in PV meaning was found in case C, where inhabitants positively transferred their active PV meaning, and identity as a zero-carbon community, to their daily practice of energy consumption through reducing their energy consumption and strictly matching their energy loads. This maintained a regular and collective monitoring process for their energy generation and consumption patterns which empowered them to sustain their positive collective energy demand management practices over time. One inhabitant stated:

> 'In terms of influencing our behaviour, we set out in the beginning to make sure that we would get the most energy efficiency appliances … also we have ongoing discussions about how can we use our appliances most efficiently.' (C4)

By contrast, the worst transformation was found in case A, where their PV meaning and value as low impact living community did not transfer effectively into their daily practice of energy consumption. This was due to the NI incorrectly assuming that all measures needed to achieve their energy saving target were fulfilled during the building construction stage. He erroneously told the other inhabitants in the community that monitoring their energy generation and consumption would not dramatically change their energy consumption practices. As a result, many of them decided not to individually monitor their energy performance despite having the know how to engage with their PV meter which would have helped them to actively match their energy loads. This passive assumption of the NI was based on the general institutional knowledge and meaning of PV system as a technology that requires very limited engagement with inhabitants, and from his short-term individual practice of PV system.

5. Conclusion

This paper challenges the traditionally dominant technological approach of introducing new technologies into homes, and justifies further debate regarding how technologies and inhabitants are considered together in academic research and policy to understand the issues of the energy saving gap in homes (Shove and Walker 2014). The findings build on the study by Frances and Stevenson (2018) by identifying the transformation of PV meaning from the provisioning side to inhabitants, and the meaning transformations between inhabitants during occupation.

The findings show that effective engagement of inhabitants with their domestic PV technology must include an examination of physical systems in detail, in their specific context, and in a relational manner (with the other practice elements). The provisioning of feedback technologies for energy generation in the PV meter and inverter, for example, should be seen within their material arrangement in homes and in relation to inhabitants' know-how and engagement, if energy performance targets are to be achieved. Know how, likewise, should always be examined contextually as a combination between the PV system and inhabitants performing the practice collectively in their real context, and in relation to the meaning and goals that users have, rather than as know-how that an inhabitant alone has to possess.

The findings further show that the design of institutional rules (e.g. standards, policies) can either greatly encourage or discourage inhabitants to engage with the PV technologies that provide effective feedback for energy generation at different times and conditions. This largely depends on whether, or not, an appropriate translation of PV meaning to inhabitants (active vs passive) has taken place in terms of encouraging energy load management through the deliberately timed use of appliances. This meaning can be effectively transferred directly through HUG/documents, as well as through wider network of actors and polices in order to improve know-how of inhabitants, and for them to perceive themselves as active participants with the technology rather than passive recipients.

The depth, reflectiveness and richness of the PV findings here are generally significant in two ways, even though they are not statistically generalizable. Firstly, the findingspresent new knowledge in relation to understanding the various socio-technical aspects that influenced inhabitants' practices of their PV systems for a particular type of housing group (community housing). Secondly, the findings indicate new areas that need to be further explored (Flyvbjerg 2006) using specific theoretical standpoints as way forward to generate further research.

A key limitation of this paper is the time span considered, given that inhabitants' practices of their PV systems and any other associated energy practices change over a longer period of time due to potential changes emerging or being introduced in any elements of practices. Another limitation lies in the relatively small number of inhabitants involved in this study and the need to carry out larger studies in relation to the findings indicated here.

Disclosure statement

No potential conflict of interest was reported by the authors.

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