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Domestic photovoltaic systems: the governance of occupant use

Abstract

Housing is responsible for 29% of all the CO_2 emissions in the UK, yet there is still limited understanding of why housing routinely uses more energy than predicted, resulting in a performance gap. Recent studies attribute this gap to insufficient use of energy efficient technologies by occupants. This paper focuses on the governance of domestic photovoltaic (PV) systems in the UK during the provision stage, a key overlooked area in the previous energy efficiency studies which have mainly focussed on PV adoption and practices by occupants but only after installation. The notion of translation in Actor Network Theory is used to analyse how a network of PV provision actants decides the system design and integration into homes, and how this in turn conditions household participation in this network. Semi-structured interviews and video tours used in four participative community and two non-participative community case studies reveal the impact of non-human actants in terms of how PV scripts and practices are formed by the PV professionals. The finding also shows that the nominated Procurement Occupants were the key mediators in the participative projects, while the housing developers were the key mediators in the non-participative projects.

Keywords: Photovoltaic systems, performance gap, governance, translation network, intermediaries, mediators, actants

Introduction

Climate change presents a critical international challenge and opportunity to transform energy governance and ensure a radical reduction in carbon emissions (IPCC, 2014; NHBC, 2015). Housing is responsible for 74% of global building energy use (IEA, 2015) and one third of the total energy consumption in the EU (Eurostat, 2013). In the UK, the housing sector is responsible for 29% of total Carbon Dioxide (CO_2) emissions, during operational use (BEIS, 2016). A successful sustainable energy strategy for housing could therefore be an effective tool for cutting Carbon Dioxide emissions significantly (BEIS, 2015; Schelly, 2016). Despite efforts to produce energy efficient homes, there is still limited understanding of why the predicted energy savings from energy-efficient technologies are not being achieved (Gram-Hanssen, Heidenstrøm, Vittersø, Madsen, & Jacobsen, 2016).

A performance gap is attributed to the practices of occupants when using energy (e.g. by increasing their indoor temperature, extending their heat season, etc.) (Gram-Hanssen, Christensen, & Petersen, 2012), and limited occupant understanding of technologies (Brown & Gorgolewski, 2015; Stevenson, Carmona-Andreu, & Hancock, 2013) as well as the poor capacity of policy and standards to deliver the projected energy performances (Baborska-Narozny, Stevenson, & Frances, 2016; Monahan, 2013). Further studies discuss the role of provision actants[1] in inscribing the material configuration and integration of these technologies into home, and their role in framing occupant practices as a result (Abi Ghanem, 2008; Gram-Hanssen et al., 2016).

UK Government action concerning low carbon housing is to reduce the role of legislation and policies (Schroeder, 2014), and instead, develop new collective action between government organisations, business groups and community groups (Healey, Cars, Madanipour, & deMagalhaes, 2002). The aim is to produce governance solutions that respond directly to user needs and capacities (Seyfang, Park, & Smith, 2013), and thus improve the use of home technologies (Chang & Taylor, 2016; Stevenson, Baborska-Narozny, & Chatterton, 2016). This paper uses the concept of governance to reveal both new realities and perspectives to include more informal and less visible ways associated with the decision making process of multiple actants (e.g. government, professionals, occupants) (Jessop, 2002; Moss, 2009) in relation to domestic technologies. The broader definition of *governance* used here is "the sum of all ways in which individuals, public agencies, and private organisations govern their common affairs in a continuous process of negotiation and cooperation" (Commission on Global Governance, 1995: 4). This paper innovatively expands the notion of governance to include the impact of non-human actants when governing a system design.

Domestic photovoltaic (PV) installation have grown rapidly in the UK housing sector due to the UK Feed-in Tariff (FIT)[2] (Muhammad-Sukki et al., 2013). This tariff was responsible for a 99% increase in the number of PV installations at the end of December 2016, and an 81% growth in capacity (BEIS, 2017). Focusing on this technology can provide deeper insights into understanding how such systems are governed by provisioning actants. A typical PV system consists of: solar panels, an inverter, a meter, AC and DC isolating switches and a wiring system as described in (Mohanty, Muneer, Gago, & Kotak, 2013). In some cases, data loggers are also installed to monitor the system performance. The meter and the inverter are potentially the main feedback mechanism for occupant interaction. 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 occupants actively log into these data.

Attempts to understand energy efficiency improvement in housing through PV systems have mainly focused on: how the system changes user behaviour and motivation (Wittenberg & Matthies, 2016), user understanding of the system (Baborska-Narozny et al., 2016; Bahaj & James, 2007; Dobbyn & Thomas, 2005; Mathieson, 1991), implementing appropriate and user-friendly feedback technologies (Darby, 2006; Hondo & Baba, 2010; Keirstead, 2007; Schelly, 2014) and occupant participation in choosing the system (Dobbyn & Thomas, 2005). These studies demonstrate that simply adding in a PV system is not enough to drive energy behavioural changes.

Other studies discuss the role of the project manager in shaping the design of a PV system (Abi Ghanem, 2008) and the challenges related to introducing PV systems with occupant load matching opportunities in housing (Baborska-Narozny et al., 2016). However, the governance of multi-level PV actants in determining the system design, material arrangements and their influence on shaping occupants' activities, has not yet been investigated. This is the main aim of this paper.

The next section of this paper explores Actor Network Theory (ANT) as a means to understand the consequential influences and impacts between the different actants involved in domestic PV provision and operation. Following a methods section, the findings and discussion section then shows how the PV provision actants shaped the system design and occupant interaction, whilst a further section shows how the participatory role of occupants influenced the system design and use. The conclusion brings all these issues together and offers key recommendations.

Actor Network Theory

Actor Network Theory (ANT) allows sociotechnical aspects of PV technology to be explored through the examination of how a network of connections is built between actants to govern a social phenomenon (e.g. PV design). In ANT, actants take their agency[3] and qualities as a result of their *relations* with other actants in a network (Wong, 2016). This means that the action of an actant is interchangeable and subject to a series of 'transformation', and is a result of the 'translation' of concepts between the various actants who are enrolled in a specific network to achieve a specific goal (Latour, 1986). Translation examines the connection between actants, rather than examining actants individually, to understand the way in which the results of negotiations between PV provision actants are translated into technological form and decide the '*scripts*' that the PV technology subsequently carries (Akrich, 1992; Kurokawa, Schweber, & Hughes, 2016).

In ANT agency is ascribed to *both* human and non-human actants (Callon, 1986). This crucially opens up an analytical space to examine the non-human actants as significant in a network (Nicolini, 2013). An actant can be either agency as "something that acts or to which activity is granted by others…An actant can literally be anything …" (Latour, 1999: 180 and 214). ANT also reveals how the governance of PV systems by occupants, alongside other actants, can influence the system design and use of the technology. This participation allows the meanings and uses of PV systems to be negotiated rather than prescribed (Murdoch, 1998).

In order to understand the different roles and capacities of actants in a PV governance network, Latour (2005) distinguishes between 'mediator' and 'intermediary' actants. The latter is a passive component of an actant network that "transports meaning or force without transformation" (p. 39) and just maintains the network. Intermediaries are a 'black box' because their outputs can be defined with knowledge of their inputs. Mediators, however, are active entities within an actor-network which implies agency in terms of decision making. They "transform, translate, distort and modify the meaning of elements they are supposed to carry" (Latour, 2005, p. 39) and, as such, the outputs of a mediator cannot be predicted from knowledge of its inputs. Other studies also preclude intermediaries from having any independent agency, with their actions solely defined by their "*in betweenness*" (Hodson, Marvin, & Bulkeley, 2013; Moss, 2009: 1481; van Lente, Hekkert, Smits, & van Waveren, 2003). Their *priorities* and *performances* are shaped by others social actors (individuals, organisations, institutions, etc.) in order to facilitate relationship(s) between them for a specific goal. The category of intermediaries also varies depending on the situation, context and their position in relation to other actants. Local government, for example, could be regarded in one context as a governing mediator and in another as an intermediary (Parag & Janda, 2014). This has crucial implications for the findings in this paper later on.

If actants are intermediaries and mediators, it follows that both intermediaries and mediators can be either human and non-human. Some studies have used the term intermediary to describe the hidden work of various organisations (human actants) that their actions are highly significant for the shifting energy governance (Bush et al., 2017; Hodson et al., 2013; Kivimaa, 2014). More significantly, other studies focused on understanding how non-human intermediaries act in a network, such as programme of work (Iles & Yolles, 2002) and planning documents and energy models (Rydin, 2013). Both human and non-human intermediaries can make connections, facilitate relationships between key actants, skills development, provide guidelines and aggregate and enable exchange of knowledge (Kivimaa, 2014). However, there exists no common conceptual understanding, or even an agreed definition, of what intermediaries are (Fischer & Guy, 2009; Moss, 2009). The paper, therefore, uses the core definitions from Latour and argues that while 'non-humans' have agency in a network, and can affect governance, this may be in terms of their 'impact' as intermediaries, rather than their 'influence' as mediators.

This distinction between intermediaries vs mediators underpins the methodological framework used here to identify, distinguish and map the way in which intermediaries work and the impact they have on the governance of PV provision actants.

Methods

A mixed methods case study approach (Yin, 2013) was adopted to provide an in depth understanding of domestic PV contexts. Two sets of contrasting housing projects in England were selected as representative 'exemplars' (Flyvbjerg, 2006: 219) to identify whether or not occupant governance influenced the PV system design and improved their interaction with it. The four selected 'Participative Community' (PC) housing projects each had a representative 'Provisioning Occupant' (PO) who was a key actant in terms of making decisions with other provisioning actants, while the other occupants in the community (community group) acted as a client. All community groups had regular meetings with their PO to ratify the decisions made by the provision actants. These projects were LILAC- Leeds (A), Fireside Co-operative- Sheffield, (B), Springhill- Stroud, (C) and Hockerton-Nottinghamshire, (D).

Two 'Non- participative community' (NPC) housing projects had occupants who bought and lived in houses constructed by a developer without their involvement in the PV procurement process and no

PO. These projects were Green Street- Nottingham (E) and Brierley Forge- Sheffield (F) (Figures 1 & 2).

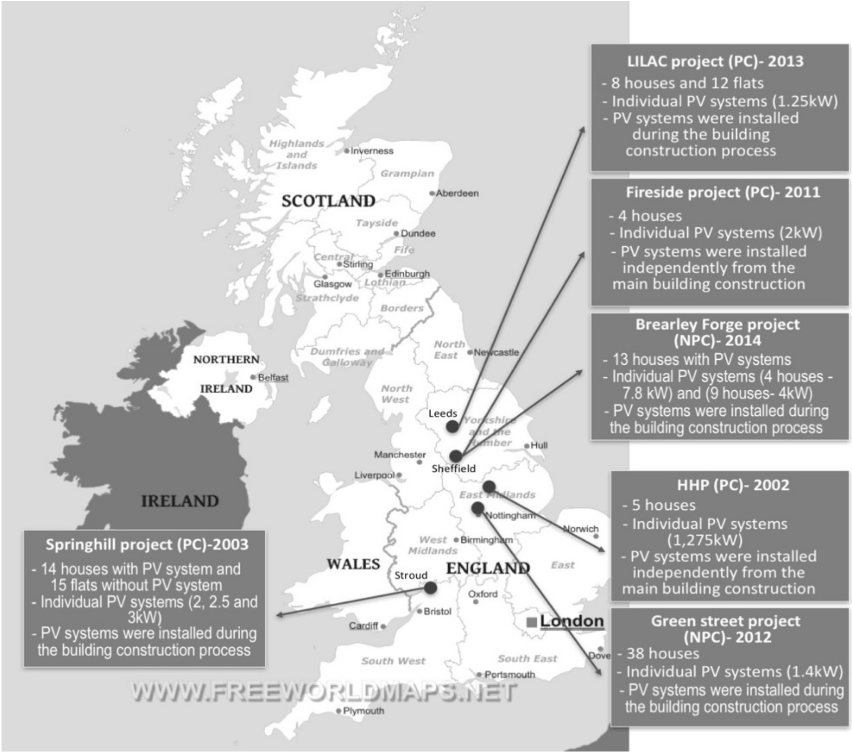


Figure 1: Details of selected case studies

LILAC Co-housing (A)

Fireside Co-operative (B)

Hockerton Co-housing (C)

Springhill Co-housing (D)

Brearley Forge (E)

Green Street (F)

Figure 2: Photographs of case studies as built

PV provision artifacts (e.g. commissioning reports, specifications, Home User Guide, and predicted performance data) were reviewed to map out the context of PV installations in detail (Stevenson & Rijal, 2010) and to help the researcher promote interactive discussion with the participants during interviews. The progress reports of UK policy related to Code for Sustainable Homes (CSH) and Feed in Tariff (FIT) show different stages with evolving standards as intermediaries. These persistent changes impact on the PV system design. In order to follow the actants and their interrelationships (Latour, 1987), 16 semi-structured interviews were carried out with PV professionals in the six provisioning teams. The interview questions were similar across all participants, and comprised of face to face, Skype and phone, or question-based interview[4] according to availability (Kvale, 2006).

In addition, 22 semi-structured interviews and 18 ethnographic video tours (Pink, 2009) were carried out with occupants to illustrate the consequences of the PV provisioning decisions on the activities of occupants in relation to their own PV systems. Innovative home video tours (Stevenson & Rijal, 2010), developed from an ethnographic walkthrough method commonly used in an energy and building context, were conducted immediately after finishing the interviews with each occupant. Traditionally, walkthrough tours have been recorded using interviews and questionnaires only (Foulds, Powell, & Seyfang, 2013; Powell, 2009). Videoing the participants using their PV controls enabled the researchers to analyse occupants behaviour when using their controls (Zeisel, 2016), identifying action possibility 'scripts' inherent in the PV meters and inverters, as decided by the provision actants, and what these 'scripts' afforded their occupants. This helped to understand how specific decisions made by provision actants influenced occupant interaction subsequently (Stevenson & Rijal, 2010), and what practical knowledge, skills, perceptions and problems occupants had when interacting with their PV controls in a real context (Pink & Leder Mackley, 2013; Spinney, 2009).

All interviews and video tours were recorded and fully transcribed. Empirical data was initially coded manually (Braun & Clarke, 2006), using two coding manuals for the data (Schreier, 2012): one for the interviews with PV professionals and POs and one for the occupant interviews and video tours . Other codes emerged freely during the analysis process, aiding the identification of specific themes (Pallasmaa, 2009). The coding was verified using an inter-coder method to increase the reliability (Krippendorff, 2004). A mapping method (Yaneva, 2012) was subsequently used to analyse the coding in relation to the critical actants in terms of whether they acted as mediators - making the decisions, or as intermediaries - impacting on the decisions. The provision data was also mapped to compare the PV governance structure in each case study, and between the two contrasting sets of housing projects, and the findings are discussed next in terms of *Professionals* and *Occupants* governance.

Governance by professionals

This section discusses professional governance of PV system and the consequence of this on occupants (Figure 3) in order to show the specific decisions made by the professionals when performing as mediators, and to identify the specific intermediaries that impacted on these decisions. 'Professionals' refers to the design and construction team and other participating agents who made decisions in relation to the system design and provision, such as the selling agency and local planning authority.

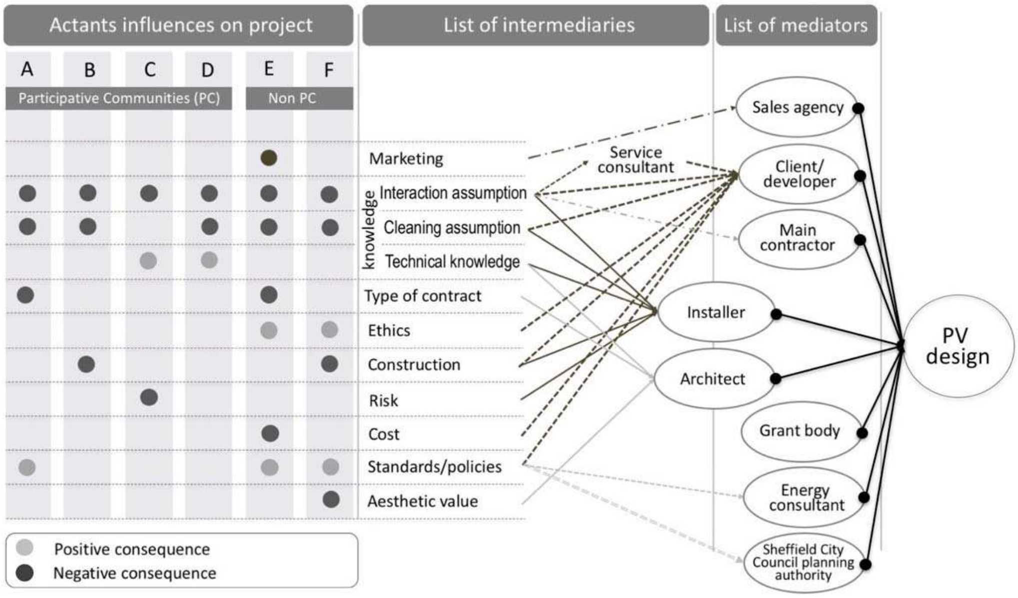


Figure 3: Intermediaries impacting on professional agencies

PC Projects

Five key professionals performing as mediators were identified in the PC projects: *architect, installer*, *energy consultant, grant body* and *main contractor*. The PO in project A employed an *energy consultant* to frame the project energy strategy at an early stage of the provisioning process who included PV systems with a minimum size of 0.75kW in each house in his final report. The *grant body* (Homes and Community Agency, England) standard was the key intermediary impacting on the energy consultant decision, in terms of ensuring that the homes were built to Code for Sustainable Homes level 4 (CSH-4). More influentially, the grant body performed a key mediator role by determining the total scale of all the systems (D), and by requiring monitoring systems to be installed in the PV systems (C, D). This improved the system script in terms of increasing occupants' capacity to compare their PV performances, to help match their energy loads and identify underperformance problems. As one occupant put it "… because we were monitoring the systems, so we picked these problems up very quickly" (D3). The mediator grant body also enabled the occupants to install their PVs by funding the systems (C, D). The main contractor as a mediator decided the location of PV meter and inverter inside homes (A), discussed later.

The *risk* factor of delayed delivery was another significant intermediary in project C. The PV meter installation in this project was delayed by 176 days, delaying also the monitoring process undertaken by the PO. Faulty fixings were another risk factor. The support frames of the PV panels were not sufficiently weighted down on the roof by the installer, resulting in them being blown over and damaged as highlighted by all interviewed occupants. Figures 4, 5, 6, 7 show how the different actants were connected to inform the system design and occupant interactions, in each of the four participative projects A, B, C, D respectively.

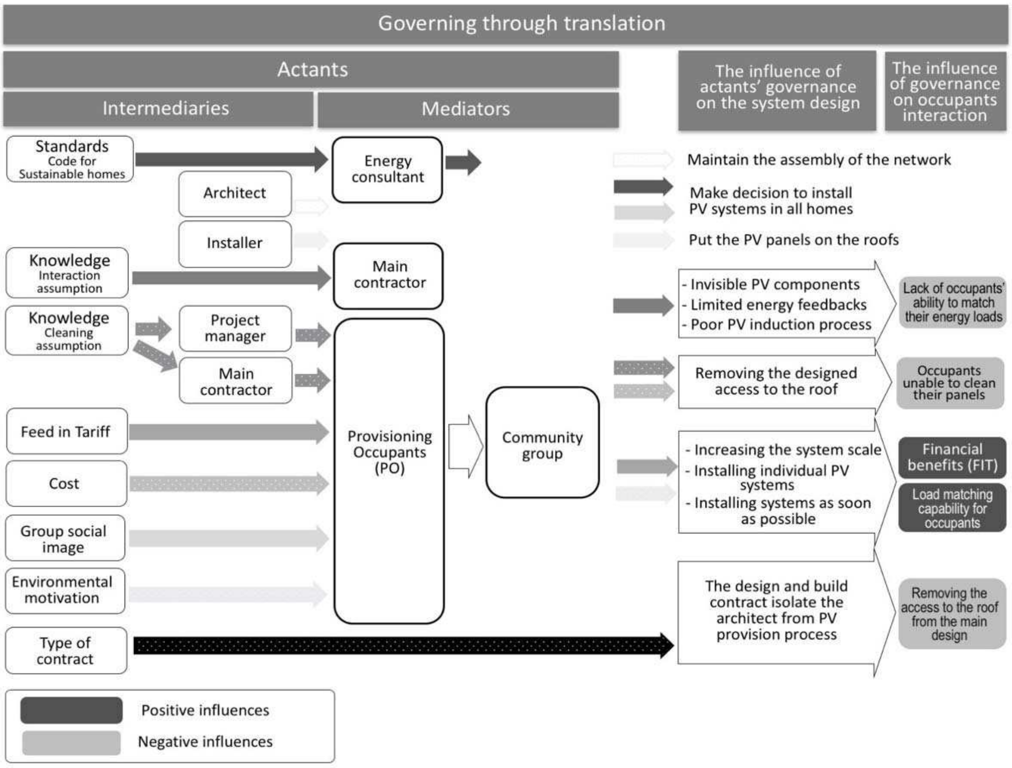


Figure 4: Professional and Occupant governance- project A

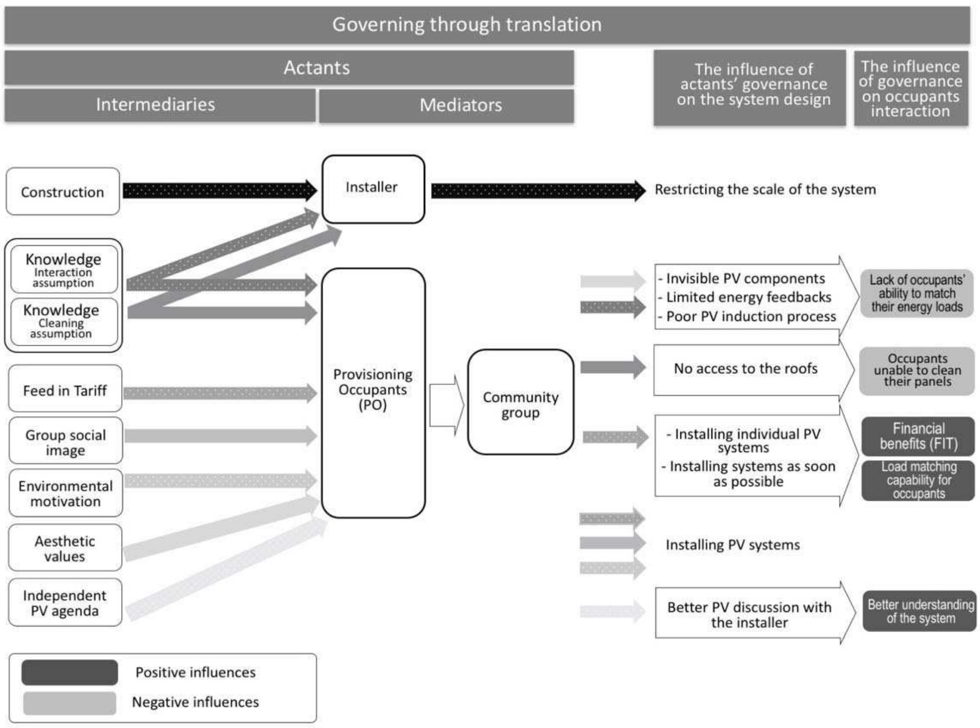


Figure 5: Professional and Occupant governance- project B

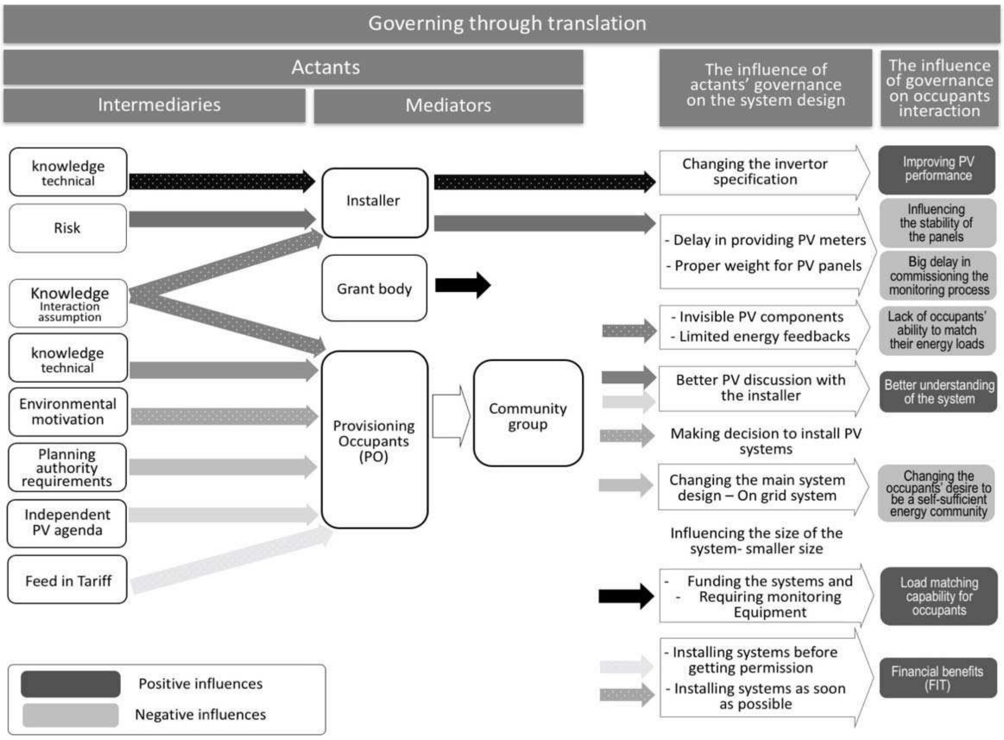


Figure 6: Professional and Occupant governance- project C

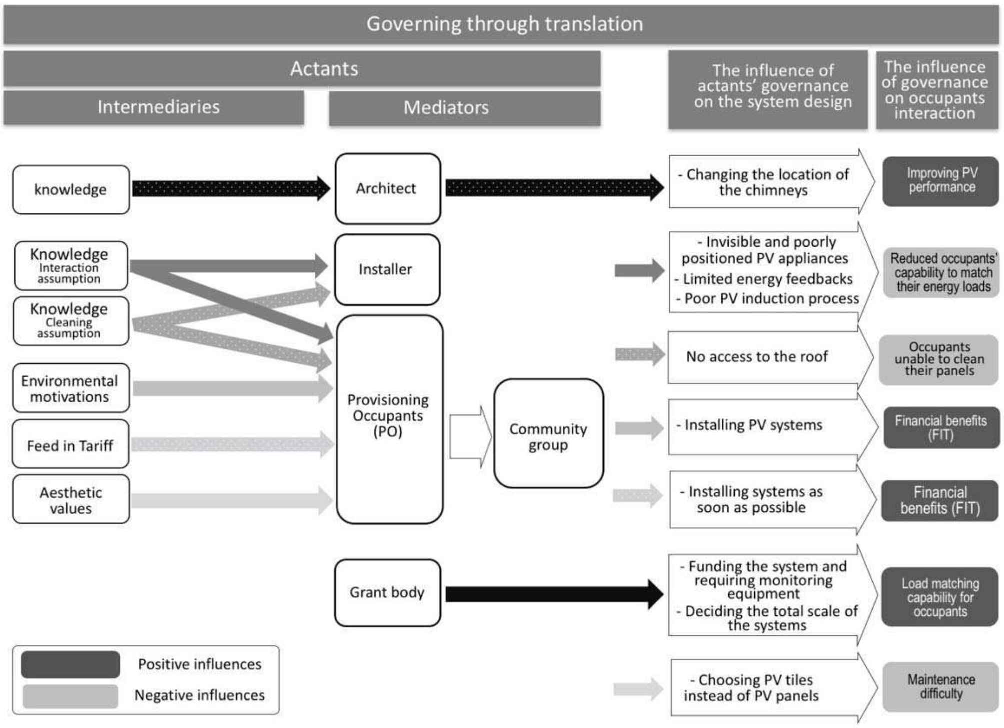


Figure 7: Professional and Occupant governance- project B

NPC projects

In these projects, the key mediators were: *the client/developer, main contractor, sales agency, Sheffield City Council (SCC) planning authority* and *the architect*. The SCC obligated the client to build new houses with 10% PV installations in project E according to their new requirements. The sustainable *ethics* principles of the developers in projects F & E impacted their decisions to install PV systems as highlighted by the Architect in project F "The client is an ethical developer and will only build new properties with a CSH score of 4".

The normative *aesthetic values* acting as an intermediary impacted on one architect (F5) to position the PV panels invisibly on inaccessible flat roofs: "we set the parameters that we felt we could accept aesthetically". His decision stopped occupants being able to see whether their PV panels were dirty or not by looking at them from the ground. The aesthetic values clearly overrode the functionality of the panels in terms of maintenance. The high *cost* factor of the PV installation acted as an intermediary to impact on the client intention and capacity to install PV systems in all homes (E). As a result, only 10% of the project homes had PV systems. The client representative suggested funding the PVs by a third party. However, this idea was rejected by the *sales agency* as a key mediator.

> "So, there were a couple of issues, around the saleability and perception, that stopped us going with this idea, with the sales agency saying: '...well every property we want to sell and if they have got a lot of PVs on the roof that would be impediment to a sale'" (E6).

Figures 8 and 9 show the overall mediators and their subsequent influences on the system design and occupant interaction in projects E & F. The figures also show the impact of different intermediaries on the mediators' decisions.

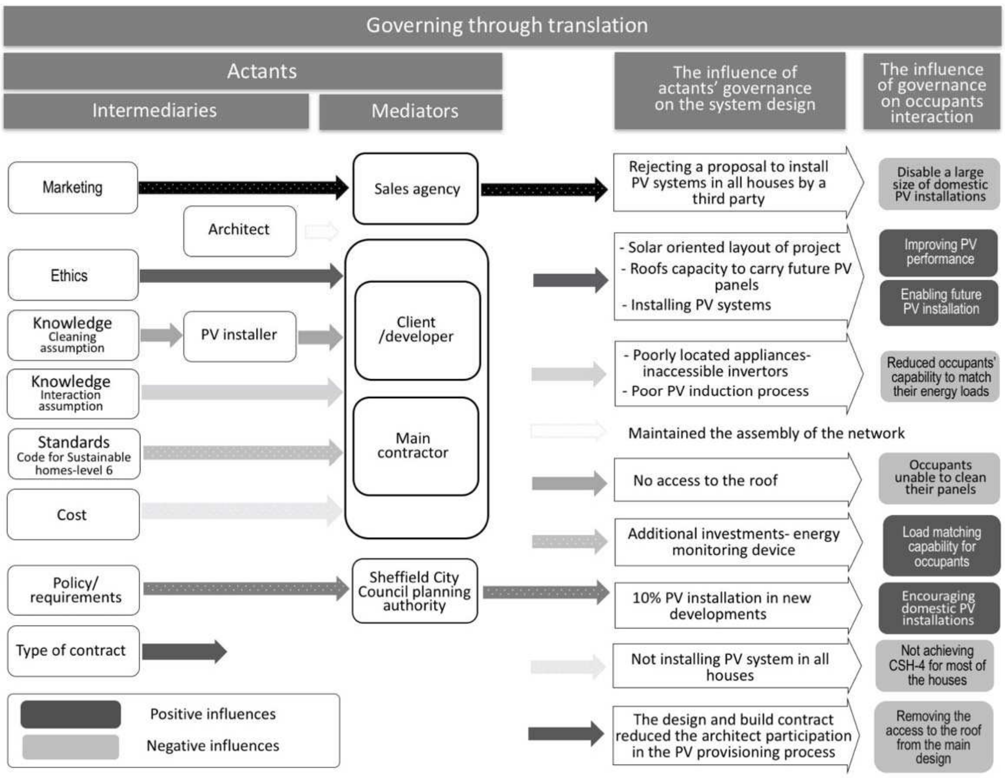


Figure 8: Professional governance- project E

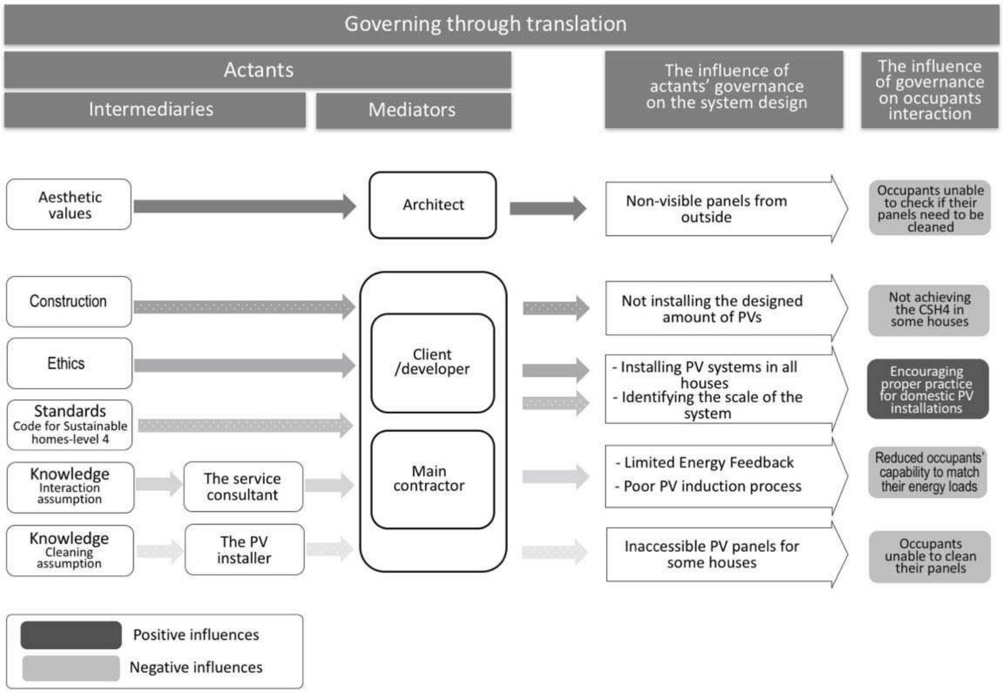


Figure 9: Professional governance- project F

Predominant intermediaries

Further intermediaries impacting on the professional team decisions in *both* the PC and NPC projects were: *knowledge, construction, standards and type of contract* as detailed below:

- *Knowledge.*

Architect (D)'s knowledge positively impacted on system performance when he changed the location of chimneys to avoid overshadowing the PV systems. Similarly, the high technical knowledge of the PV system installer led him to change the specification of the inverters to match the PV panel generation rate, again improving the performance: "…the installer changed it to 1100E instead of 1200E…And I think that was because the inverter will work more efficiently" (C1).

By contrast, the assumption made by various professionals that PV panels were self-cleaning resulted in all PV panels being inaccessible except in project C. One PO even made the decision to remove the roof access to the PV panels from the main design, impacted by the cost and assumption intermediaries: "we took out the accessibility to the roof from the design for cost issues… the panels were self-cleaning as far as I'm aware, so they would not need regular cleaning" (A3). An occupant in project D illustrated the consequences of this assumption:

> "…Sycamore trees … have very sticky deposits that come down from them on the PV panels, which does not get cleaned by rain...so, we are actually generating a lot less energy from other

houses here…I have managed individually to clean about 2-3 of the arrays, the other 4-5 arrays beyond them are just getting dirtier and dirtier and I can't reach those" (D1).

The PV installation guide documents did not mention cleaning requirements (MCS, 2012). However, some PV websites do mention physical panel inspections or checking via a monitoring system (Solar Facts and Advice).

Worryingly, in the NPC projects, cleaning issues were not mentioned at all because the occupants did not know their own PV energy generation, or even if their system was working: "So, I have got the system, but I don't know anything about it … we don't even know if it switched on." (E1). Two other owner occupants also did not know if their panels needed cleaning because they did not have any feedback to tell them whether their system was generating the expected energy.

Similarly, the assumption by PV provision teams that the PV inverter and meter needed no real occupant interaction (apart from quarterly meter readings for the FIT) significantly impacted on the material script for the system: "…the technology is in the house and just sits there passively doing stuff for them and they don't need to do anything, just need to full the form to get the FIT and read the meter to claim benefits" (client representative-E6). This resulted in insufficient provision of direct monitoring feedback to occupants for the PV system performance (D, F) and energy performance (all PC and NPC projects) which reduced the capacity of occupants to match their energy loads. The other significant impact of the above assumption concerned the material arrangement of the system appliances inside the house. Three video tours revealed inverters located in a small room and/or in a very low or high position restricting occupants from being able to read the display screen or changing the setting of the information (A & B) (figure 10). The problem was made worse when the inverters were located by the developer in an attic (NPC Project E). Tellingly, when asked about the inverter, one occupant replied "I don't know anything about it? What it does look like" (video tour E1).

Figure 10: Inverters location- A

- *Construction.*

The PV provision team had to significantly reduce the size of the planned PV systems in some houses due to improper governance by the architect in relation to the roof size (B, F) due to insufficient prior discussion between the architect and the PV system designers in project F.

> "There were two homes where the roof size were insufficient to accommodate enough PV panels – the size that was designed to achieve the A score. So, for those homes we just put PVs as much as we could" (interview, project director F).

- *Standards.*

The high requirements of the Code for Sustainable Homes (CSH) level 6 standard, as an intermediary passing on government environmental policy, impacted on the developer in project E, who installed a smart monitoring device, described by one occupant as:

> "… a nice device that could help you to get a sort of idea about how much your system is producing energy and how much you are using the electricity at the same time in a very visual way… *"* (Video tour E3).

These requirements also impacted on the developer, who increased the scale of the PV system from 4kW to 7.8 kW in four houses to achieve level 6 'zero carbon homes'. In project F, the CSH level 4 standard (44% reduction in dwelling emission rate below building regulation standards) impacted on the client, who installed PV systems in all houses.

- *Type of Contract.*

In projects A and E, the design and build contract acting as an intermediary by passing on client decisions, impacted on the capacity of the architect to actively support the translation process with some critical decisions being made without his consultation. Examples include: removing the access to the roof in project A and installing the inverters in an inaccessible place in project E.

Governance structure

A clear difference in the governance structure was identified between the two sets of housing. In the PC projects, the POs performed both mediator and intermediary roles during the PV provision process. They made all the key decisions during their discussions with other professionals (figures 4, 5, 6, 7), while also acting as intermediaries by passing on decisions to the occupants. Importantly, only one way translation occurred from the design team to the occupants through the PO in all PC projects, as the PO did not take the view of occupants back to the design team in relation to the PV system design. This could be attributed to their belief that the design team people were *experts* with better knowledge than the occupants leading them to accept all the suggestions made by the professionals without challenging their decisions. Furthermore, the POs were more aligned to the design team than to the occupants when discussing the final decisions with the occupants, moving from a basis of neutrality and changing their PO role as intermediary to mediator, persuading the occupants to accept all the design team decisions.

In terms of other professional governance, the energy consultant and the main contractor performed as mediators in project A, making key decisions in relation to system design and integration into homes, while the rest of the provision team, particularly the project manager, acted as intermediaries who impacted on the decisions of the PO. In projects B, C, and D the installer informed as mediator because the PV system was independently installed from the main building construction. He decided the system design and integration into homes directly with the PO, and influenced the POs' final decisions of their system in terms of locating the monitoring device in an invisible place (B, C), and not providing accessible PV panels to clean them (B). In project A, the installer had a different role, acting only as an intermediary who maintained the assembly of the actants. The grant body acted positively, as a mediator by determining the overall size of the PV systems (D) and requiring a monitoring system to be installed (C, D). The architect acted only once (project D) as a mediator during the PV provision process due to the PO commissioning him separately from the construction process. The architect was relatively powerless in the other projects as an intermediary.

In the NPC projects, the client/developer, the sales agency, the Sheffield city council planning authority and the main contractor were the mediators who made the key PV decisions in both projects, impacted on by other intermediaries (figures 8, 9). The architect acted as a mediator only in project F through his independent role in the provision process. However, the occupants had no agency at all when governing their PV design and remained ignorant of system performance and maintenance, as discussed earlier. In both NPC projects, the installer acted as intermediary who only maintained the assembly of the network by installing the specified PV systems, and impacted on the client decision in terms of not providing accessible PV panels to clean them.

Knowledge proved to be the most significant intermediary (all projects), followed by standards and ethics (NPC projects), and FIT, environmental motivation and aesthetic (PC projects) (figure 4). The professional *assumptions* about PV system interaction clearly impacted on the governance of the system design and reduced the occupants' capability to interact with these systems effectively. Importantly, where a provision team had specific technical knowledge, this generally helped them to improve the PV system performance in terms of energy generation.

No actant in any project taught occupants how to interact effectively with their PV appliances and manage their energy loads when they first moved into their homes. No occupants in the NPC projects knew how to use their inverters and energy monitoring device: "I don't interact with it because I don't know much about its application" (Video Tour E1). In the PC projects, only the POs were aware of how to use their own inverters, while the other occupants were not, because the PO did not *transfer* their knowledge to other occupants – a vital omission. Lacking an understanding of their system, therefore, is not simply the 'fault' of the occupants as has been highlighted in the previous studies, but more significantly, it is also the fault of the providers and POs decision-making with a lack of prioritisation.

Occupant governance

P*articipation* played a key relational role in helping occupants to govern their PV system design and their subsequent interaction with it, as discussed next in detail.

Governance at preparation stage

Five key intermediaries impacted on the decisions made by the PO and community groups, and the PV system design as a result: *Independent PV Agenda*, *Feed in Tariff, environmental motivation, social image, and planning authority requirements*. (Figure 11).

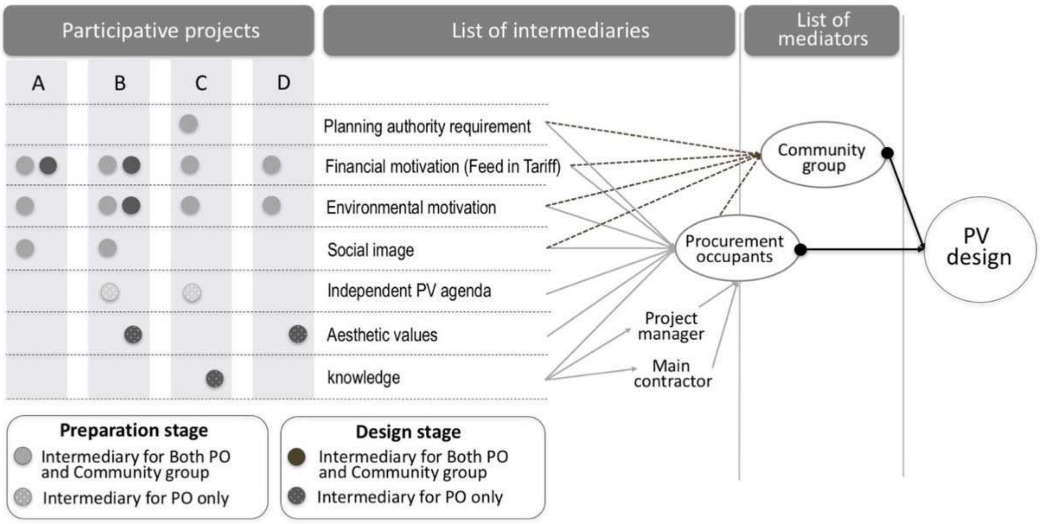


Figure 11: Participative occupant governance

For all community groups, the Feed in Tariff (FIT), as a vehicle through which the government decisions are passed on to clients, and environmental motivation were the key intermediaries when making the decision to install PV systems: "… as a group we decided to have a very low impact on the environment." (C1). Occupants sometimes linked their PV system with an opportunity to demonstrate a visible green agenda '*social image*' highlighting another significant intermediary. (A and C- Figure 12): "Well, we joined the community, which was going to be ecologically oriented. Therefore, it would be very odd if we did not have solar panels on the roof" (A2). The reduction in the FIT tariff impacted on the decision by occupants to install the PV systems quickly in all PC projects. In some projects, an individual system was installed in each house instead of one big community system (A, B). These decisions enabled occupants to apply for the FIT, and to individually monitor performance and match their energy loads:

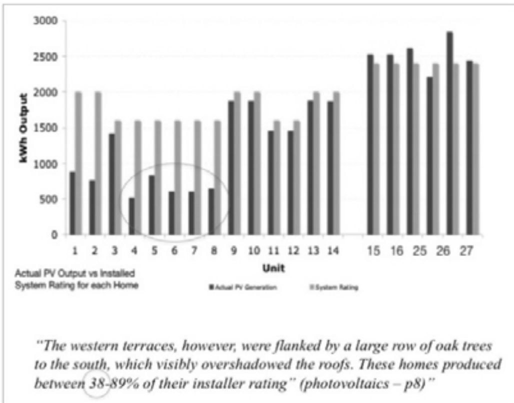
> "...we could understand the energy production from PV system for each house…so we could fit our energy consumption with our energy production such as changing the time of using washing machine or the kettle…" (Interview- B3).

The main intermediary impacting on the occupants' decision to have On-grid PV systems instead of Off-grid PV systems (C) (with more resilience following grid failures) was the requirements of the *planning authority* which granted a separate PV permission from the main building construction. Crucially, the *independent PV agenda* (B, C), with the PV systems installed independently from the main construction process, allowed the PO to have individual PV meetings and discussions with the installer directly. This was very informative in terms of improving the POs PV technical knowledge.

Governance at design stage

Four key intermediaries impacted on the system design decisions by occupants at the Design stage in the provisioning process: *Feed in Tariff (FIT) and environmental motivation (*PO and Community group*), knowledge* and *aesthetic values (*PO only*)*. The occupants at this stage governed the scale and the cost of the systems (A, B and C), while in (D), the grant body governed the scale and cost of the systems. One PO (A) said that the FIT drove him and his community group to make a decision to *increase* the scale of their individual systems from 0.75kW to 1.25kW, trading off the extra capital cost against long term savings. In another project the occupants *decreased* the originally designed scale of the systems in order to leave room for future solar thermal installation: "we made a decision that we wanted to leave a space on the roof for putting solar thermal panels afterwards" (PO- B). This shows that installing PV systems means different things to occupants who apparently have a similar commitment in relation to reducing carbon emissions. Some people install PV for immediate financial gain while others install it for environmental gain. This could be attributed to the different PV meanings that the POs gained through discussion with other professionals and passed on to other occupants in relation to the provision of their PV system.

Where the PO had technical knowledge (C), discussion occurred concerning the influence of chimney overshadowing on the PV system performance and PV panel maintenance, but this did not occur in all PC projects. This resulted in identical PV systems performing very differently in terms of their energy generation. Due to unmitigated *overshading by trees,* the predicted PV system energy generation was significantly lower a (60%) in project D, as calculated by Pasquale, Gill, and Firth (2013) compared to the minimised *overshading by the chimneys* in project B resulting in only 5% reduction on predicted energy generation as calculated by the occupants (figure 12).



Actual energy outputs vs projected rating for each house in project B

Fireside pv performance - year 1 Summary				07/08/2011-05/08/2012
House	Projected	Actual	Difference	% error
55	1634	1710.4	76.4	4.70%
57	1634	1568.1	-65.9	-4.00%
59	1634	1647.2	13.2	0.80%
61	1634	1632.8	-1.2	-0.10%
Total	**6536**	**6558.5**	**22.5**	**0.30%**

Fireside pv performance - year 2 Summary				05/08/2012-04/08/2013
House	Projected	Actual	Difference	% error
55	1634	1734.7	100.7	6.16%
57	1634	1592.8	-41.2	-2.52%
59	1634	1656.8	22.8	1.40%
61	1634	1659.6	25.6	1.57%
Total	**6536**	**6643.9**	**107.9**	**1.65%**

Figure 12: PV performance gap in Projects D and B

Worryingly, no design teams gave any consideration to tree overshadowing, despite a clear reference to this in the PV panel installation requirements (BRE, 2006) creating a significant performance gap. Either the design teams were not properly trained to understand and apply this requirement or, they de-prioritised this requirement in terms of its *meaning* to them- a deeper point that needs to be considered. In fact, the project manager thought the tree shadow problem in project D happened because "…… people are putting them (PV panels) in not quite the right place, because they got them for free, and people would be happy even if the systems were not generating energy perfectly" (D6). A champion, as new intermediary, is needed on the provisioning side to ensure that all the PV installation requirements are covered at each stage.

Aesthetic values had a clear impact on the PO in project B to locate the PV appliances in the cellar, which reduced occupants' motivation to monitor their energy use in order to match their energy loads (Video tour B3). These values also impacted on one PO who chose PV tiles instead of PV panels even though one occupant stated that they expected difficulty in replacing the broken PV tiles "because you have to lift all those tiles and retile them, then maybe that has implications for a new structure underneath" (D1).

By mapping all PO and community group intermediaries across all projects (figure 11), it is clear that the *FIT, environmental motivation, social image* and *independent PV agenda* were the most significant intermediaries that had an impact on the governance of POs and community groups in the preparation stage. In the design stage, the *FIT* was the key intermediary that had an impact on both the POs and community groups decisions, while *aesthetics* and *knowledge* were the main intermediaries that impacted on the POs only. The overall governance structure of both Professionals and Occupants is illustrated in figure 13, which shows the complete list of intermediaries that impacted on the decisions made by the various mediators, and the PV system design as a result.

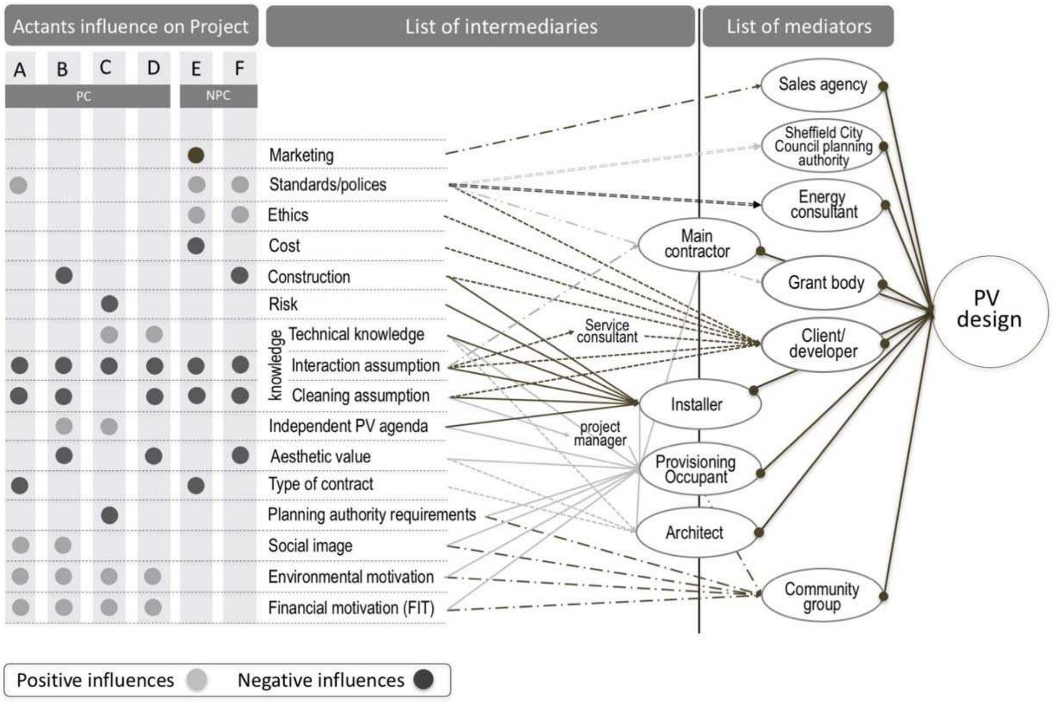


Figure 13: Professional and Occupant governance

The overall governance limitations during the preparation and design stages of the procurement process (PC), and their negative consequences on occupant interaction with PV appliances, is illustrated in figure 14.

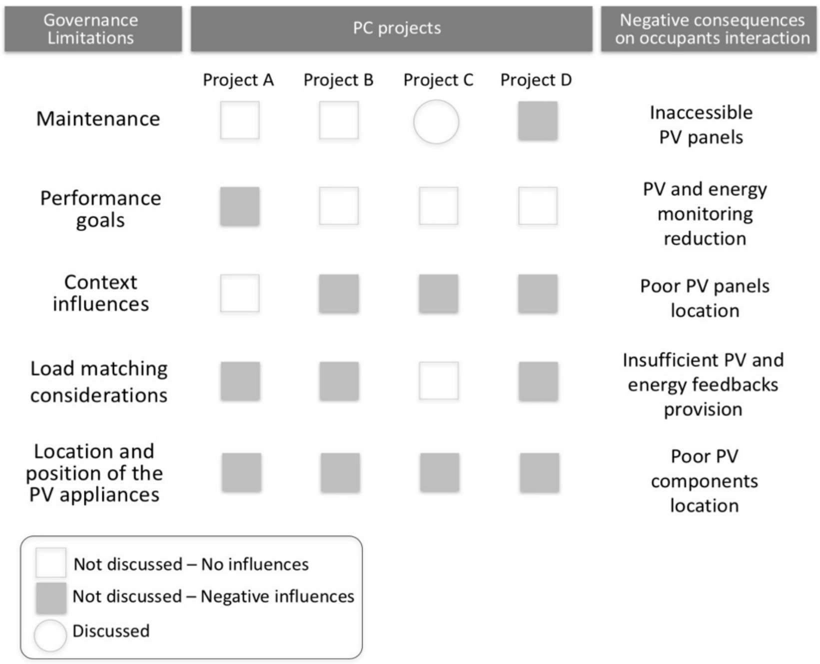


Figure 14: Occupant governance limitations

There was no effective governance by the PO in relation to the location and position of the PV inverters and meters when discussing the PV design in all the PC projects. This resulted in a hidden and poorly illuminated inverter (A and B), and poor positioning of PV meters and inverters (A, C and D): "We never talked about the location of the PV parts through the design stage until I saw them… the inverter is hidden and in low position so I can't see the display easily" (PO-A3).

Failure by the PO to discuss performance targets with occupants in all PC projects also reduced occupant capability to benchmark their own PV system efficiency. However, the collective monitoring process in these projects enabled occupants to understand the relative performance by comparing energy usage with neighbouring houses:

> "So, individually we looked at the figures and compare the results. It was very interesting and useful because we have detected the problem of underperformance of our PV system and asked for suggestions" (D1).

This collective monitoring process is a significant intermediary that needs to be more understood in relation to governing PV systems effectively.

Conclusions

This paper has introduced a new approach to addressing the performance gap associated with the use of domestic PV technologies and energy efficiency, by extending the governance concept within ANT in relation to provisioning and consequential usage. It has creatively explored how the various professionals govern the provisioning of PV systems and the impact of various intermediaries on their governance. The findings represent a significant contribution to an area that has been underestimated in previous research. The innovative combination of video tours with interview analysis, adds further insight.

Importantly, the ANT notion of translation shows that the system governance is not a predictable or fixed model of production. Instead, it is a result of the negotiation of conflicting priorities and visions embodied in a variety of actants who are enrolled in a specific network and context. Using the governance concept with ANT has also helped identify and explain the significant role of non-human acting as intermediaries for the shifting governance of the PV systems. Their crucial impact on the decisions made by PV provision actants performing as mediators, needs to be acknowledged when negotiating the system design and specifications at the provisioning stage.

POs play a key role as mediators in the PC projects when governing the system scripts with the provision team. This is effective when they have knowledge of the technology system and can have an independent PV agenda and discussion with the installer to ensure good system design in terms of energy generation and better understanding of PV performance and maintenance. These roles were absent in NPC projects, where the client and the main contractor are generally the key mediators, resulting in occupants remaining ignorant about their PV energy production– a major concern, as NPC projects make up the majority of housing in the UK. Ideally, POs should act as neutral intermediaries during their meetings with all occupants when passing on design team governance decisions and specifically not aligning themselves with the design team visions. This can empower occupants with active agency in the translation process by ensuring their visions and interests are exchanged with the design team.

The non-human FIT intermediary have a big impact on the PV outcomes in the PC projects in terms of scale, system design and the installation time frame - all designed to improve the energy generation from the supply side and to increase the financial benefits. By contrast, the FIT had no impact on the system design in the NPC projects; instead, the energy standard and developer ethics usefully impacted on developer decisions to install PV systems in the first place, and greatly impacted on the scale of the systems alongside other intermediaries, such as the roof size and cost.

Critically, there is generally an incomplete translation during PV provisioning in terms of the location of the PV panels and inverter due to poor participation of the architect and the PO when governing the system integration in homes. PV cleaning requirements and load matching opportunities were not translated via written documents, resulting in poor PV meter and inverter specifications and locations, and inaccessible PV panels.

Key professional governance limitations need to be addressed to help improve the effectiveness of future domestic PV projects. The most critical limitation concerns the poor decision making around the location of the PV appliances inside the home, especially in NPC projects.

This study is limited in scope while rich in depth. Further research involving a larger study of PV provision actants, particularly the architects and PV installers, is needed to provide a broader understanding of how the material arrangements come to be as they are in a variety of housing tenures. This can help ensure best practice which mitigates climate change while empowering occupants to take responsibility for their use of energy and thus help change their behaviour.

Key recommendations arising from this study are:

Practice:

- Professionals need to accurately consider: overshadowing, correct specification of energy use for the available roof area, PV panel cleaning and energy management requirements, and correct inverter specification for the specified DC load. New intermediaries (both training personnel and detailed guidance and documents) are required for PV professionals, to ensure this level of detail is not ignored at the preparation and design stage, and for them to understand the different influences their governance can have on occupants' practices.
- Aesthetics should always be considered by PV appliance designers strictly in relation to effective occupant interaction.
- PV installations should always enable occupants to be able to check if the panels need cleaning.

- Effective installation of load-matching equipment should be included in certification courses for installers. PO's should also be well-trained as mediators, in order to efficiently govern system design and integration into homes, acting through their own knowledge rather than relying only on other experts, who can fail.

Policy:

- Financial incentives need to be designed to encourage users to match their energy loads rather than simply installing PV systems for financial profit.
- Grant bodies should specify PV monitoring requirements which encourage occupants to load match directly, and to ensure that all the installation requirements are covered in different stages via appropriate guidance and other intermediaries.
- Building standards should require PV supplied homes to be provided with integrated load matching feedback equipment, located in clearly accessible and visible locations, and to be introduced to the household by a suitably qualified professional as intermediaries.

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Endnotes

[1] According to Latour, the word 'actant' refers to both human and non-human in a network.

[2] FIT consists of two payments made by the energy supplier: *generation* and *export* tariffs. For the generation tariff, the energy supplier pays a fixed rate for each kW that has been generated, while an extra payment for the exported energy to the main grid would be also received and assumed to be at the level of 50% of energy generation (Energy Saving Trust, 2014).

[3] Agency refers to the actants capacity to influence actions and decisions in a network (Latour, 2005).

[4] participants were sent all the interview questions and they replied by email or paper format.