Emerging energy transitions: PV uptake beyond subsidies

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Abstract

In the past decade there has been a substantial increase in the uptake of residential solar photovoltaic (PV) systems globally, which is starting to impact upon traditional electricity systems. An emerging energy transition is being driven by actions taken by actors at the grassroots level, and enabled by declining technology costs and new niche business models. However, to date, most work exploring change in energy systems has tended to focus on technological innovation and economic processes, leaving social aspects and daily activities under-addressed. Similarly, most theories that consider individual behaviour have tended to neglect the wider system of change. This paper presents an approach for simultaneously exploring behavioural and systemic change and demonstrates its use in a case study of PV uptake in New Zealand. The Energy Cultures framework is used alongside the Multi-Level Perspective of socio-technical transitions to examine the broad range of factors driving, shaping, and constraining PV uptake, and the interactions between global and national landscapes, the socio-technical regime within which users are taking action, and the niche opportunities emerging. Taking an integrating approach allows these perspectives to be brought together, providing valuable insights as to how adoption might be promoted or constrained, and the implications this may have for the future management of electricity grids.

Highlights

- Energy Cultures Framework guides analysis of user behaviour and drivers for change.
- Multi-level Perspective used to explore niche and incumbent actors in transition.
- Combining perspectives provides richer insights into grassroots led transition.
- Implications of PV uptake understood through user, niche, and regime interactions.

Keywords

Socio-technical transition; behaviour change; grassroots innovation; energy culture; social practice; photovoltaic (PV) uptake

1 Introduction

PV uptake, particularly when it occurs in dense pockets, challenges the traditional socio-technical electricity regime. Rather than energy being generated in centralised power stations and distributed to end-users, households that have PV are using less centrally generated electricity and some are using it in different ways (Keirstead, 2007; Bahaj and James, 2007; Dobbyn and Thomas, 2005; Erge et al.; 2001; Haas et al., 1999). High levels of adoption are starting to shift electricity market dynamics (Rhys, 2016) as well as raise concerns around social equity (Macintosh and Wilkinson, 2011) due to the high costs associated with the technology making it largely prohibitive for many. Therefore, advancing our understanding of the factors that shape PV uptake, and the potential impacts on the electricity industry, existing infrastructure, and society more broadly, is now essential.

Most electricity systems in developed countries were built at a time when fuel was plentiful and cheap, and when the adverse climate impacts of carbon based fuels were unknown. This is now no longer the case. Increases in both population numbers and appliance ownership and use have resulted in growing demand for energy (International Energy Agency, 2014a), while decreasing upfront costs, global agreements to reduce carbon emissions, and financial incentives have resulted in a rapid uptake of privately owned residential PV systems across many countries (Tyagi et al., 2013; International Energy Agency, 2014b). Traditionally facilitated through feed-in tariffs, many households are pushing power back into the electricity grid; consequently, changes to requirements and standards around managing the grid are being increasingly considered (for example, the UK's Future Power System Architecture Project[1]). Network congestion, voltage rise, and rapid changes in output (e.g. due to fast moving cloud cover) are all problems that are starting to emerge because of PV proliferation (Eltawil and Zhao, 2010). More recently, decreasing prices for battery storage (Nykvist and Nilsson, 2015) combined with new business models (e.g. lease schemes, solar as a service options) provide the opportunity for more homes to install PV, and even become disconnected from the grid altogether, leaving fewer customers to cover the costs of running and maintaining existing centralised generation assets.

These shifts in electricity systems are emerging through behaviour change of actors at the grassroots level afforded by both declining technology costs and new niche business models. However, to date, most approaches considering individual behaviour have tended to neglect the "complexity and influence of the social, economic, and political context in which those behaviours are manifest, arise, and develop" (Capstick et al., 2015: page 436). Similarly, most work to date exploring change in energy systems has tended to focus on technological innovation and economic processes, leaving social aspects and daily activities under-addressed (Shove and Walker, 2014).

In this paper we aim to explore how behaviour change and system transition approaches can be brought together to provide a more comprehensive view of change, exploring PV uptake in terms of actor behaviour (and behaviour changes) as well as in the broader context within which this is occurring. We analyse a combination of primary and secondary data to investigate the factors driving PV uptake in New Zealand, which has risen sharply since 2012 (New Zealand Electricity Authority).

[1] https://es.catapult.org.uk/what-we-do/fpsa/

The New Zealand case study is particularly interesting to explore because these sharp rates of uptake are occurring despite lack of financial incentives, resulting in a net-present negative value for consumers (Wood, Miller and Claridge, 2013). The continued rate of PV uptake in New Zealand points to an emerging transition in the energy system that requires a consideration of the dynamics surrounding consumer behaviour. In this paper we use the Energy Cultures behaviour framework (Stephenson et al., 2010, 2015) alongside the multi-level perspective on socio-technical transitions (Rip and Kemp, 1998; Geels, 2011) to guide an exploration into the broad range of factors affecting PV uptake across a range of contexts. Bringing these perspectives together helps provide valuable insights as to how policy interventions might promote or constrain adoption, and the implications this may have for the future of energy systems.

2 Socio-technical Transitions in Energy

Socio-technical transitions describe a shift in the technology, markets, user practices, policy and cultural meanings relating to key societal functions (Geels, 2002, 2004; Elzen et al., 2004). Access to safe, reliable and affordable electricity underpins daily activity, enables modern society to function, and is one of the key enablers of economic growth (Modi et al., 2006; IEA, 2013). The shift from centralized power plants (mainly fossil fuel based) to distributed generation is a topical example of a socio-technical transition in energy underway globally. Understanding how these energy transitions occur, the patterns and mechanisms involved in the transition process from one set of energy behaviours to another, and the implications such transitions may have on future energy behaviour, are critical to ensure sustainable asset management and understand the potential technical, social, market and regulatory challenges.

Energy transitions have a number of unique characteristics that distinguish them from other types of transition or behaviour change in different domains (Geels, 2011; Verbong and Geels, 2010; Mah et al., 2012; Markusson et al., 2012). The first is that they tend to be purposive, driven by pressing environmental issues and sustainability goals that are expressed through national and international pressure. Second, solutions that offer the greatest collective good may not offer direct or tangible benefits to end-users, and this may have political and economic implications that require consideration. Finally, the energy sector tends to be dominated by powerful incumbent firms, many of whom have invested in existing infrastructure. Shifting away from this is not a fast or easy process, and may influence the degree to which incumbents support the transition, which could either constrain or accelerate the adoption of new technologies. Energy transitions thus encompass change across technology, practices, markets, and culture, implemented through a variety of interconnected actors. Understanding energy transitions requires a theoretical approach that incorporates this multi-dimensionality, as well as the structural change within which transition is situated.

2.1 A Multi-level Perspective on Transition

The multi-level perspective (MLP) provides a useful lens through which to consider socio-technical transitions in energy systems. Drawing insights from evolutionary economics, sociology of technology, history of technology and innovation studies, the MLP supports the analysis of long-term system dynamics, shifts from one socio-technical system to another and the co-evolution of technology and society (Geels, 2002, 2005; Elzen et al., 200; Geels and Schot, 2007).

In the framing provided by the MLP, transition is defined as the change from one sociotechnical regime to another (Geels and Schot, 2007). This regime shift incorporates technological developments, rules, and engineering practices, as well as broader characteristics such as the regulatory environment, policy, culture, markets, and user preferences (Rip and Kemp, 1998; Geels, 2002). Socio-technical transition results from the non-linear interactions between the socio-technical regime, niches (the locus for radical innovations), and the exogenous landscape (Geels, 2002, 2004, 2011).

The MLP has predominantly been used to study historical transitions within specific sectors (e.g. Ansaria and Garud, 2009; Geels, 2005, 2006a, 2006b; Konrad et al., 2008; Raven and Verbong, 2007; Sovacool, 2009; Verbong et al., 2008). It provides a broad framing to explore multiple pathways of transition resulting from different interactions between the three levels in the framework (Geels and Schot, 2007). While studies to date have tended to focus on transitions emerging from the alignment and expansion of niche technological innovations, an increasing number of authors are pointing to the importance of exploring how everyday activities may drive (or prevent) transition (Shove et al., 2012; Jones and Murphy, 2011, Hargreaves et al., 2013; Geels, 2012). Furthermore, demand and lifestyle considerations, particularly relating to actors within civil society settings who have the potential to play a vital role in generating grassroots innovation and socially embedded behavioural changes, remains under-addressed (Berkhout et al., 2004; Shove and Walker, 2010; Genus and Coles, 2008; Seyfang and Smith, 2007). Indeed, further research is required to explore how social, value-driven innovations emerging from behaviour changes contribute to transition within mainstream systems (Seyfang and Longhurst, 2013).

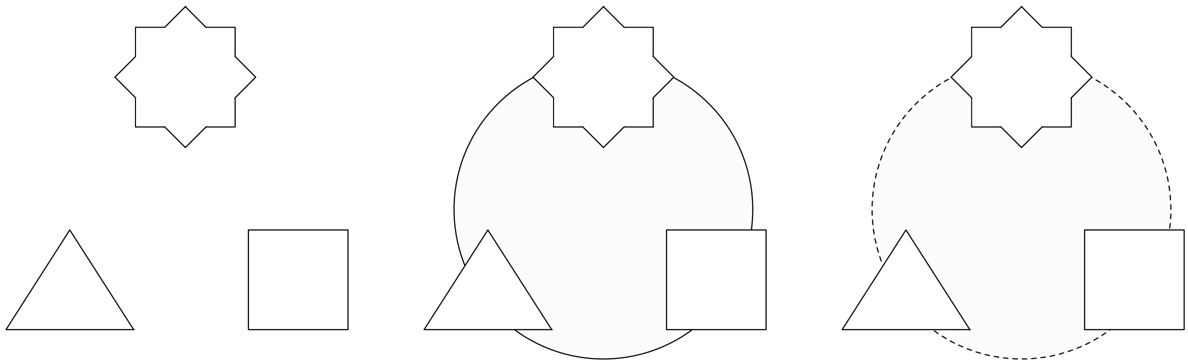
Overall, the MLP provides a useful conceptual framework for exploring socio-technical *systems* in transition, directing attention to niches, regimes, landscapes, and their interactions, and exploring how innovations can be shaped by social processes (Geels, 2010; Lachman, 2013; Hargreaves et al., 2013). However, as Shove and Walker (2010) suggest, the links between social processes and technological transition is often more dynamic, and consequently, we see that additional insights from other theoretical perspectives are required to explore how activities of civil society actors are constrained by and interact with this wider system.

2.2 Everyday Activities and Theories of Practice

One such perspective that has become widely used in exploring transition is Practice Theory, which builds on a wealth of socially-orientated approaches (e.g. Giddens, 1984; Bourdieu, 1992; Wilk, 2002), and has more recently been applied to sustainability transition (e.g., Pantzar and Shove, 2010; Shove and Walker, 2007, 2010, 2014). Practice theory provides a different and additional perspective to explore sustainability transitions. This approach considers how social practices are sustained, reproduced, or shifted through various processes and rituals occurring in everyday life, exploring the practice itself as the unit of analysis (Shove and Walker, 2014; Watson, 2012; Spurling et al., 2013). Consequently, it provides a perspective beyond the frequently used more simplistic models that consider social change to be the outcome of values and attitudes driving behaviours that individuals choose to adopt (Shove, 2010). Practice theory instead shifts the focus onto the practices that underpin daily activities, for example in their analysis of Nordic walking Shove and

Pantzar (2005) examine the 'images' (meanings, symbols), 'skills' (know-how, forms of competence), and 'materials' (artefacts, technologies) to understand the practice itself and the way in which it becomes constituted as practice. As depicted in Figure 1, the continual interaction between these elements by those performing practices serves to develop (i.e. from proto-practice to practice), maintain, or break links (i.e. from practice to ex-practice) between particular images, skills, and materials, thus forming, changing, or fossilising practices (Pantzar and Shove, 2010).

Figure 1: Formation, maintenance, and dissolution of practices (adapted from: Pantzar and Shove, 2010, page 450)



Repetition of practices through continual reinforcement of links between images, skills and materials can cause lock-in, and transition stemming from lifestyle and practice change may require destabilisation and breaking between these elements, changing the nature through which activities are enacted (Pantzar and Shove, 2010; Hargreaves et al., 2013, Gram-Hanssen, 2011). In this work it is the duality between actors (i.e. the performers of practice) and the structure or context in which their actions both are enabled and reproduced (Giddens, 1984) that is of particular interest in our exploration of transition. Practice theory thus provides a useful lens through which to explore the interaction between images, skills and materials in creating, sustaining, or breaking practices, placing the practice itself as the focus of enquiry. This perspective also accounts for the routinized actions of actors, who are understood as carriers of practices (Shove, 2010).

However, rather than focussing on practice changes associated with a shift in materials (i.e. PV technology), this work aims to explore the lifestyle and contextual factors affecting the acquisition of PV, and how this in turn can lead to wider socio-technical transition. Instead of considering actors as carriers of practice, it is the actors and their behaviour[2] that is at the forefront of this analysis; this work aims to explore how activities, mental processes, and contextual influences give rise to a shift in technology (i.e. the adoption of PV) by households.

According to Shove (2010), social theories of practice and those of behaviour are like "are like chalk and cheese" (page 1279). She argues that the former emphasise endogenous and

[2] We use the International Energy Agency Demand Side Management Task 24 definition of behaviour, which states that energy behaviour refers to all human actions that affect the way that fuels are used to achieve desired services, including the acquisition or disposal of energy-related technologies and materials, the way in which these are used, and the mental processes that relate to these actions.

emergent dynamics considering people as carriers of practice, whereas the latter focus on causal factors and external drivers, considering people as autonomous agents of choice and change. This suggests that social practice theory is not an appropriate frame for the analysis of household behaviour change. However, this work aims to go beyond such a simplistic model of behaviour in exploring how household behaviour gives rise to PV adoption, recognising that: (1) societal behaviour is complex, interactive, and interdependent, and (2) understanding change needs a consideration of how external and internal contexts, beliefs, actions, and their inter-relationships, shape behaviour (Crocker and Lehmann, 2013). Thus, we frame our exploration of transition to make the actor and their behaviour – rather than the practice – the unit of analysis, and turn to recent work on energy culture to support such an exploration of sustainability transitions.

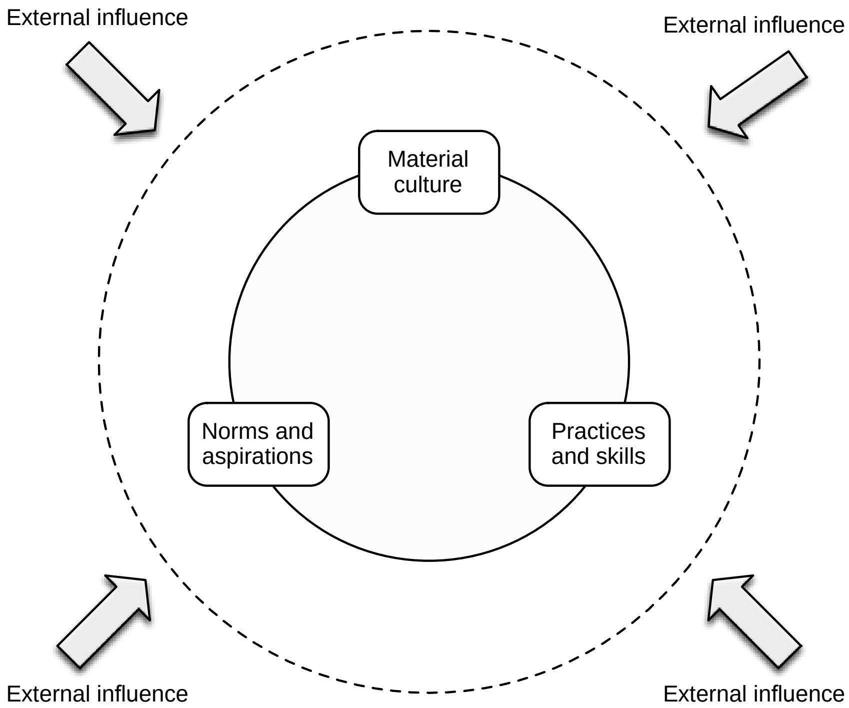
2.3 An Energy Cultures Approach

The Energy Cultures framework (Stephenson et al., 2010; 2015) was originally developed in 2009 to meet the needs of a multi-disciplinary research team who were seeking an integrating model to support enquiry into energy behaviour. It “took cues from multiple theories and explanations of behaviour, and aimed to bridge the divide between research traditions centred on the individual and those focused on wider social and technological influences” (Stephenson et al., 2015: page 117). Since its first publication it has been used to support enquiry into a variety of topics, including timber companies use of drying technologies (Bell et al., 2014), the impact of different home energy advice approaches (Scott et al., 2016), mobility and the future of transport (Stephenson et al., 2014; Hopkins and Stephenson, 2014; Hopkins and Stephenson, 2016), individuals’ actions on greenhouse gas emissions (Young and Middlemiss, 2012), and energy behaviour in higher education in Malaysia (Ishak et al., 2012).

From the perspective of the Energy Cultures framework, each actor or group of actors has a distinctive energy culture – a combination of their material culture, norms, and practices relating to the use (and transformation) of energy. ‘Material culture’ – akin to Practice Theory’s ‘materials’ – refers to physical artefacts including buildings, infrastructure, appliances and other technologies. While Practice Theory considers these as the materials that enable or constrain societal practices, the Energy Cultures framework sees these as the materials over which an agent has control or influence *and* which may affect their energy demand. Similarly, ‘Norms and aspirations’ is akin to a particular instance of Practice Theory’s ‘images’; it encompasses both the expectations users hold of a particular service or behaviour and their aspirations for the future, which are often shaped and influenced by the meanings and images they attribute to the behaviour or service.

‘Practices’ has historically been used in the Energy Cultures framing to refer to the usual or customary actions carried out by the actor/group of actors (Stephenson et al., 2015). It refers to “both routinized activities and to actions that may occur relatively infrequently in the life of a subject, yet which are a common occurrence across their social peers” (Stephenson et al., 2015: page 119) In this way, ‘practices’ incorporates everyday actions as well as the acquisition of material objects that enable them to enact and reproduce social practices. However, an actor’s skills and competencies that often enable them to undertake such action is not make explicit in the framework. We believe that these underlying abilities, which are crucial to enabling action, must be articulated when considering behaviour and transition. In this work we extend the energy cultures framework to encompass ‘skills’ and competencies along with actions; thus expanding ‘practices’ to ‘practices and skills’ to cover both actions that are done and actions that actors are able to do (see Figure 2).

Figure 2: The Energy Cultures Framework



For any given actor or group of actors their “energy culture” consists of the interplay between these factors (material culture, norms and aspirations, and practices and skills), which is shaped, although not fully determined, by external influences from the structure (or in MLP terms, the regime and landscape) within which it is embedded. Energy cultures may in many circumstances become locked in when norms, practices and material cultures are strongly self-reinforcing, when skills and aspirations are aligned with existing practices and material culture, and/or where external influences in the prevailing regime and landscape support the status quo. However, change does occur, and this can be stimulated through actions undertaken by actors (e.g. to adopt new technology), and/or through influences from ‘outside’ (e.g. higher energy prices).

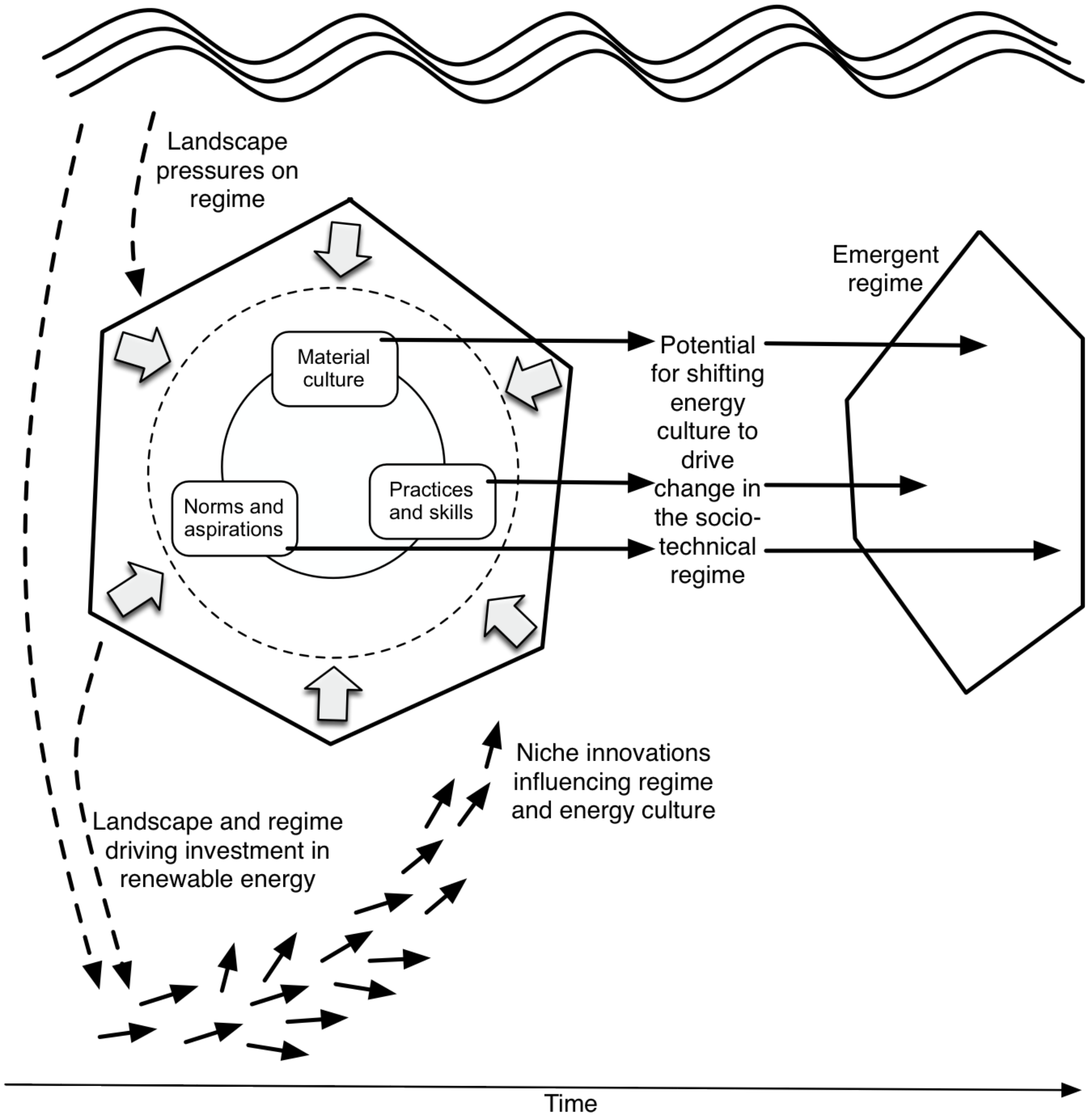
2.4 Connecting Energy Cultures and the MLP

One way in which the Energy Cultures framework complements the MLP is that it invites a focus on actors and agency – that is, the capacity of given actors or groups of actors to make choices and create change. While the MLP focuses on the role of actors in structural change, the Energy Cultures framework focuses in on the actors themselves; bringing these perspectives together can help identify how change within an actor’s energy culture can stem from the wider socio-technical system and can ultimately lead to change at a structural level.

Through the MLP lens, transitions from one socio-technical regime to another incorporate shifts in the technological regime, as well as a shift in the broader concepts of regulatory environment, policy, culture, markets, and user preferences (Geels, 2002; 2004). From a technological perspective transition encompasses change in the “rule-set or grammar embedded in a complex of engineering practices, production process technologies, product characteristics, skills and procedures, ways of handling relevant artefacts and persons, ways of defining problems; all of them embedded in institutions and infrastructures” (Rip and Kemp, 1998, p. 340). Opening up the transition space to also consider behaviour (i.e. through the Energy Cultures lens) we consider energy transitions as emerging from actions and behaviours of a wide variety of actors. Accordingly, in this context, we broaden Rip and Kemp’s (1998) definition to one which considers a change in the *energy culture emerging from an inter-related set of practices and skills, material artefacts, and norms and aspirations, embedded in a particular social and physical context as established by institutions and infrastructures* (see Figure 3).

To date, most research using the Energy Cultures framework has focussed on the elements over which a particular actor has agency (i.e. their own material culture, norms, or practices), and has viewed external influences having a one-way influence on actors (e.g., Bell et al., 2013; Stephenson et al., 2014). However, at times actors may have the ability to change the structure within which they are embedded through the collective impact of their change in energy culture. We suggest that if changes in the energy culture of independent actors reach sufficient critical mass, this can start to influence the nature of the regime through dynamic interactions between material culture, practices, and norms with the wider socio-technical regime (and the incumbent actors) and niche innovations and spaces. The way in which such interactions may play out and the circumstances under which shifting energy culture (in this instance through the uptake of PV) may play a role in wider transition of particular interest in this paper, and we aim to address this by bringing together insights from the Energy Cultures framework with those from the MLP.

Figure 3: Shifting energy culture stimulating social-technical change (adapted from Geels and Schot, 2007, page 401)



3 Method

To investigate the factors that shape uptake, we employed a multi-pronged research approach, combining interviews with early adopters of PV, interviews with stakeholders in the supply, distribution, and management chain, data from a household survey rolled out across New Zealand, and data from a choice modelling experiment and survey. System dynamics modelling techniques were then drawn on to provide structure around the identified themes, and to make explicit the causal relationships between different variables surrounding PV uptake.

3.1 Interviews

Eighteen semi-structured interviews were conducted with people who had either already installed PV, were in the process of installation, or were considered to be community level experts on the topic of PV. They were conducted face-to-face and sixteen were one-on-one; the other 2 were conducted with husband and wife pairs. Interviews were with households in Blueskin Bay, a suburb close to Dunedin on the South Island of New Zealand that has experienced several community-led initiatives (facilitated by the Blueskin Resilient Communities Trust, or BRCT), which have coalesced around aspirations for improving resilience in the region. The Blueskin area was selected due to the community's considerable interest in PV, enabling a wide variety of household types to be recruited (see King et al., 2014, for more information). Participants were not financially incentivised to participate, but were rewarded with a large bar of chocolate at the end of the interview.

An additional 19 interviews were conducted with adopters of PV in two regions of the north Island in New Zealand. These were telephone interviews with households who were customers of either Vector or WEL networks[3]. All telephone interviews were one-on-one and no participants were incentivised financially to participate.

The interview questions were designed to help identify the key factors involved in the adoption of solar PV, and any subsequent shifts in energy culture. This resulted in the interviewees being asked about the following:

1. Norms and aspirations relating to micro-generation, to establish what participants understand, think, and feel about PV;
2. Processes and actors involved in supporting the journey from interest/contemplation to serious consideration and purchase of PV;
3. The role of social norms and community actors in supporting the uptake of PV;
4. Internal and external drivers and barriers to change; and
5. Energy related activities before and after PV adoption.

A further four interviews were conducted with stakeholders and community experts who had some involvement in PV in the Blueskin area and/or the wider Dunedin region. These interviews were conducted to explore the broader context and gain additional perspectives on PV uptake in Blueskin Bay. Two were conducted face-to-face, and two were telephone interviews.

All interviews were recorded and transcribed verbatim. A thematic analysis was conducted on the information collected from the interviews to draw out the significant themes and codes from the data. The interpretation of these themes was guided by the Energy Cultures framework, which provided basis for considering the interrelationships between material culture, energy practices, norms and aspirations, and contextual influences.

3.2 National household survey

Data were collected between 16th April and 15th June 2014. The survey was administered online, and participants recruited via a commercially sourced panel. The survey took approximately 45 minutes to complete, and asked questions about a variety of household

[3] Vector and WEL networks are two of the twenty-nine electricity distribution companies who manage the medium and low voltage power networks in New Zealand.

energy and mobility issues. A subset of questions were asked to gain insight into New Zealanders' knowledge, interest, and aspirations around microgeneration and solar PV. A total of 2278 surveys were completed and analysed. For the purposes of this paper only frequency analyses on those survey questions relating to sample characteristics and PV are reported.

3.3 Choice modelling experiment

To further understand the degree to which New Zealander's are interested in PV, and the particular attributes of the PV system that are relatively more important, a choice modelling experiment was conducted in 2014 via an online decision-making platform[4]. A total of 2038 participants were recruited via a commercially sourced panel provided by Research Solutions Ltd. Of these, 1018 participants were asked about PV systems (the remaining 1020 were either asked about electric vehicles or home energy management). In addition to this choice modelling experiment, participants were also asked questions about their knowledge and interest in PV. All participants filled out an attached survey that collected basic demographic information.

Data were analysed to identify knowledge levels around PV, interest in purchasing PV, and intention to purchase within a pre-defined time frame. The relative utility of each of the attributes explored in the choice modelling was also identified to provide insight into methods by which PV offerings might be made more or less attractive to households. These data were also explored to identify demographic differences across responses.

3.4 System Dynamics Modelling

Systems dynamics modelling was used to explore the non-linear social dynamics and feedback loops between different aspects driving, enabling, or preventing PV uptake. First, members of the research team involved in the interview, survey, and choice modelling work, participated in workshops or one-to-one interviews to develop a series of cognitive maps. This cognitive mapping technique, developed by Eden (1988), is a method through which peoples' perspective of a situation and/or issue can be visually recorded to depict how key ideas are connected.

The initial workshop used cognitive mapping techniques to tease out the key ideas emerging from the different research streams about factors driving PV uptake. By capturing these ideas, referred to as concepts in the cognitive mapping method, in the form of a visual map, the interpretation of their meaning is made explicit enabling it to be tested and validated. The initial workshop captured 42 distinct concepts and the links between them that people considered were relevant to an understanding of PV uptake.

Because of the large number of concepts these maps can become densely populated and hard to interpret. To begin to unpick the relationships between factors affecting PV uptake a centrality analysis was conducted to identify - from the large number of connected concepts - which ones were central to the ideas being explored. These 'central' concepts are the ones that have the densest connections influencing, and being influenced by, other concepts, and they are important because they are potentially key factors that will have the most significant impact on PV uptake. The final analysis teased out the feedback loops existed

[4] https://www.1000minds.com/

within the concept map. These loops are circular arrangements of causally connected concepts (Capra et al., 2014). They are important because they account for major drivers of change or stability in systems, so understanding them gives some insight into how the system could evolve over time.

4 An Energy Cultures Lens on PV uptake

4.1 Material Culture

Most interview participants owned their own homes; 69% owned their home debt-free and 28% with a mortgage. Compared to the national household survey, where 31% owned their homes debt free and 35% with a mortgage, the early adopters of PV are far likelier to own their own homes. The correlation between home ownership and PV uptake has been documented in prior research (Mills and Schleich, 2009), and it is understandable that few people would be willing to invest significant sums of money in a property that they did not own. Early adopters interviewed in this research were also unwilling to install PV on a property in which they were not intending to live in for an extended period of time.

4.2 Practices and skills

Being well informed about PV and energy efficient practices more generally were strong characteristics emerging from the interviews. It was clear from the discussions with interviewees that their energy literacy levels were generally very high. Some interviewees had particularly strong technical knowledge about energy, including about different aspects of micro-generation systems. Most interviewees were careful about their energy use, and many had taken active measures to improve efficiency and/or reduce electricity consumption. Most households interviewed were also able to describe a wide range of energy saving activities that they undertook. For some, the installation of PV was the next step in a journey to a more energy efficient home. Furthermore, the ease with which they could install PV and the ease of maintaining it was a real draw.

Within Blueskin Bay, several of the interviewees had technical backgrounds, and it was often these interviewees who had also done considerable amounts of research on PV, many becoming very credible experts in particular renewable generation topics.

4.3 Norms and aspiration

Interviews with early adopters showed that the desire to purchase PV was supported by aligned norms and aspirations around energy more broadly. The rising cost of electricity was a key motivator for many, who no longer wanted to be tied to power companies. Many households interviewed lacked trust in their power companies and wanted some protection against future rises in power prices.

> *"Power prices have gone up 24% in three years, and they're going to go up more, now that they're selling them off. My philosophy is to be as sustaining and in control – as much I as can – of my own outlays."*
>
> David, 45-54 years, homeowner

The national household survey (Wooliscroft, 2015) backs up these interview findings, revealing that only 30% of people are happy with getting their electricity from their power company; 58% would like to generate their own electricity, 38% while remaining connected to the national grid, and 20% being independent of it. These are aspirational responses but give an indication of a very widespread desire for independence.

Those interviewed also expressed a desire for greater financial control over their own outgoings. The decision of whether to install PV was much more of a pragmatic financial decision, and PV was seen as an economically sound option for some interviewees planning for their retirement. A few interviewees who were earning a salary, but were going to be moving onto a fixed income while still resident in their current home, saw investment in PV as a way of reducing future outgoings.

> *"Why wouldn't you want to have an extra something that would make your [electricity] payments less in the future? You're creating your own power, and power's really expensive, so you can't go wrong. It's a saving for that person, so I can't see it [having PV installed] as a disadvantage really."*
>
> Patricia, 35-44 years, homeowner

The concern over future electricity prices and financial expenditure was similarly reinforced by the national household survey. The majority (approx. two thirds) of the national household survey respondents indicated that they were fairly or very concerned that in the next 5-10 years electricity and gas will become unaffordable for them. A number of the interviewees were also thinking about their retirement, and the benefit that PV would afford them in terms of reduced outgoings when they stopped working. This financial argument was further supported by the decreasing cost of solar panels and installations.

> *"You know, we're in our fifties and they're probably not even going to give us a pension when we get old. So we have to have as much happening as possible. Because electricity is a huge cost."*
>
> Susan, 45-54 years, homeowner

As well as the lack of trust in power companies and a desire for greater power price insulation and financial control, grid independence was perceived as being important by some, particularly in providing resilience in the face of power cuts and/or natural disasters. It is also interesting to note that there seems to be a belief amongst at least some interviewees that grid-connected PV systems still operate when the grid is down. This is not necessarily the case and in many installations the system had not been set up to achieve this – however this does indicate a market opportunity to provide this service.

4.4 Contextual Barriers

One of the main barriers to uptake was the high upfront cost of the PV units. Allied to this was the lack of financial incentives through feed-in tariffs in New Zealand.

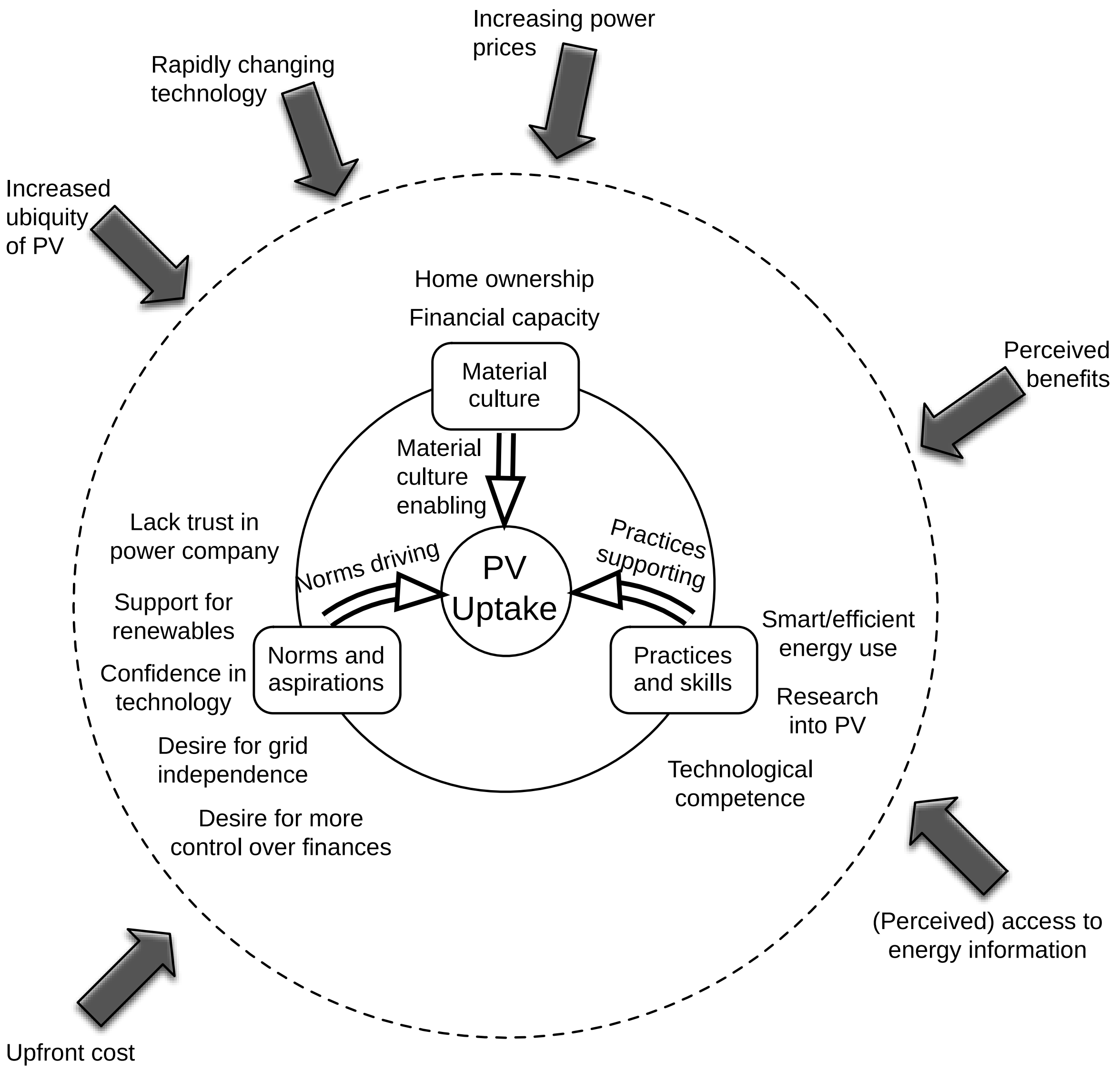
> *"Basically, I'm loath to progress [with the PV installation] until I'm in a situation where I have a feed-in tariff. Otherwise I'm faced with either capital expenditure [on batteries] which is difficult to do, or a situation where most of the power that's generated, I can't use, because I'm away from the house most of the day."*
>
> Richard, 65-74 years, homeowner

The uncertainty around return on investment due to the lack of certainty about buy-back rates was also a cause for concern for some, although others did not appear to be concerned about these matters. A few people suggested that some form of government intervention should be used to encourage or mandate PV to be installed on new builds.

Some people also talked about uncertainty with regards to changes in PV technology. The rate at which the technology is improving and costs are dropping made some people question whether now was the right time to invest; *"Is the technology going to be so much better in a few years time? So is it worth waiting a bit longer `and saving up the money?"*. However, the increasing ubiquity of PV panels in New Zealand, and particularly in Blueskin Bay, was itself a driving uptake as people saw that PV was in fact possible.

The Energy Cultures Framework allows us to visualise how these different elements come together to drive and support the uptake of PV in New Zealand, as illustrated in Figure 4.

Figure 4: The Energy Culture of Early Adopters



5 A Multi-Level Perspective of Transition

Whilst the Energy Cultures Framework helps explore factors driving, preventing and enabling the uptake of PV, it is limited in supporting an understanding of how landscape and niche factors shape the regime within which such behaviour occurs. Here the MLP is more useful at situating a consideration of landscape changes, both within New Zealand and globally, as well as identifying how niches are emerging and starting to drive cracks in the regime.

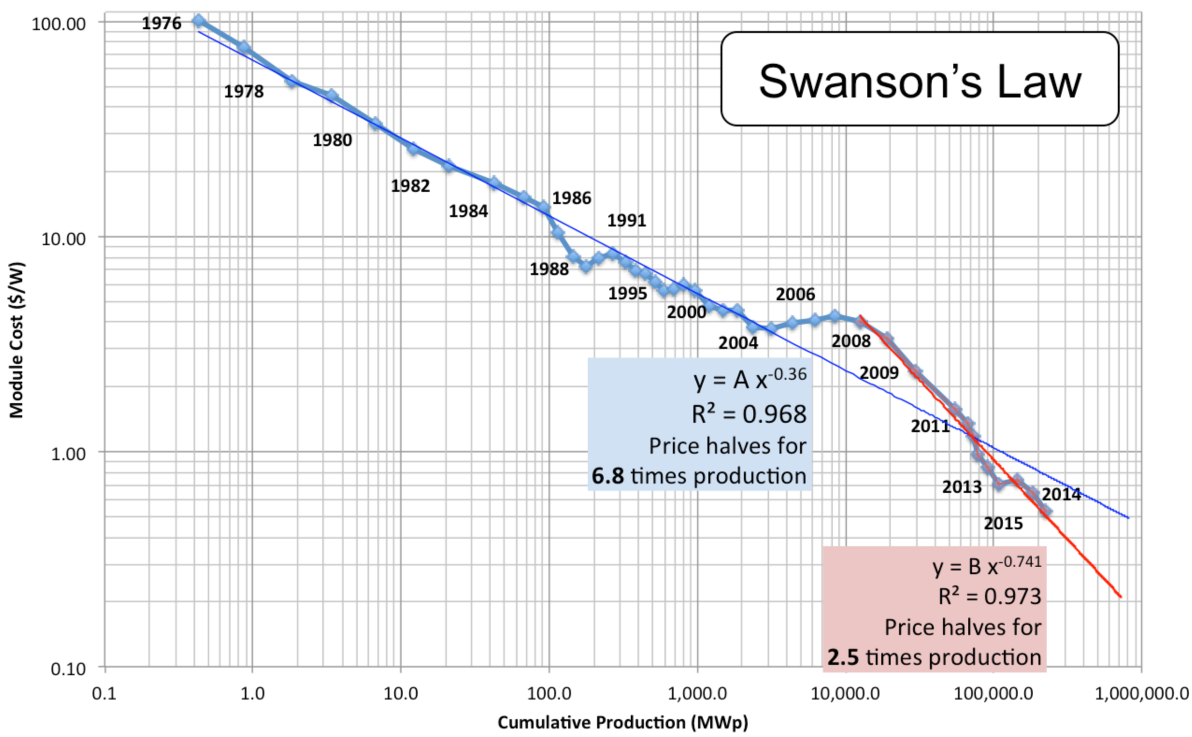
5.1 New Zealand's Energy Landscape

New Zealand has high levels of renewable electricity; in 2015, renewables made up 80% of the total generation mix[5], with hydroelectricity accounting for 57%, geothermal for 17%, and wind for 5%, while the main non-renewable resources were gas (15%) and coal (4%). In addition, while the New Zealand government recognises the untapped potential of solar, wave and biomass to increase beyond 80% renewables, their energy strategy (MED, 2011) doesn't place any targets for growing these resources. Thus it is perhaps unsurprising that no government led subsidies exist to promote the growth of solar resources.

As noted by Miller et al. (2014) "the reason why some parts of the world are so far ahead is heavy subsidies for PV, generally through attractive feed-in tariffs" (pg. 4). As of 31 January 2016 there were 8738 solar installations– low compared to countries like Australia, UK and Germany, but (in contrast to these) purely market-driven. However, the growing global demand for solar PV is driving up production and driving down costs as niche technologies grow into mass markets. The rate of cost reductions compared to cumulative production has been accelerating, and since 2008 the cost of PV has been halving every 13 months.

[5] Electricity data tables are provided by New Zealand's Ministry of Business, Innovation, and Employment. See http://www.mbie.govt.nz/info-services/sectors-industries/energy/energy-data-modelling/statistics/electricity for further information.

Figure 5: PV module costs according to cumulative products (Eyre and McCulloch, 2016)



5.2 The Socio-technical Regime

The New Zealand electricity sector is comprised of many incumbents spanning generation, transmission, distribution, and retail. New Zealand has five major electricity generating companies, who are also the main retail companies (and often referred to as 'gentailers'). Transpower, a state owned enterprise, owns and operates New Zealand's national electricity transmission system, which includes substations, high voltage cables, transformers and overhead lines for transmitting high voltage electricity. Within New Zealand there are 29 different lines companies who are responsible for distributing power from the transmission network to end-users. Most of these are owned by trusts, but there are also other models including public listings, shareholder co-operatives, community trusts and local bodies. Most lines companies sell their services to electricity retailers who provide a bundled service to consumers (who are free to switch between retailers), inclusive of power plus distribution and transmission costs.

In New Zealand, the lack of subsidies for solar means that, despite the reducing costs of technology and installation, PV systems are an uncertain investment; the lack of subsidies combined with financial uncertainties remain a significant barrier in New Zealand. Initially, consumers were able to sell power into the grid for the same prices as they purchased from the grid (close to $0.30/kWh). However, electricity retailers and distribution companies who profit under the current regime stand to lose business and face stranded assets if rooftop PV becomes more widespread, and are creating barriers to entry and structural pressure to resist change. Although uptake is fairly low to date, concerns are starting to appear around current pricing mechanisms and retailers and distribution companies are trying to limit the uptake of PV through reducing buy-back rates and lobbying against government incentives.

"Well I think that if NZ had a regulated independent power-purchase agreement for small scale generation or even a feed in tariff, people would just do it. You'd get that loan and do it straight away. It would make complete and total sense. So the financial side is definitely a barrier. A barrier that could be eliminated with re-regulation to encourage a fair price. So that's a really simple barrier that could be eliminated."

Mark, community energy expert

In other areas, distribution companies seem less worried about the impact of PV, though do acknowledge that higher rates of uptake would be cause for concern. As rates of PV uptake continue to increase this could have increasingly negative impacts on the existing regulations within in the electricity sector. Some distribution companies are expressing concern over how they can recover the costs of their assets, which is currently done on a volume of power delivered basis. Increasing PV could serve to reduce consumption for those with PV, resulting in the remainder of the grid-connected population having to pay more per household under existing business models. Increasing grid costs may then serve to make PV more attractive to those who can afford it. This is reflected in the data from a national household survey, where a substantial proportion of those people who report to either own or who intend to purchase PV have a higher than average income (Wooliscroft, 2015). However, pockets are emerging where higher rates of uptake and uptake by non-typical households are driving this niche energy technology toward the mainstream.

5.3 Niche Community Actors Enabling Change

Despite low uptake of PV nationally, one example of where installation rates are much higher is within the Blueskin Bay community. As of September 2014, The Waitati Substation zone (i.e. for Blueskin) represented only 6% of the region's network connections, but comprised 70% of installed distributed generation capacity. Within the area we are seeing accelerated uptake, as this niche technology starts to find its way into the mainstream. Here, the Blueskin Resilient Communities Trust (BRCT) have embarked on a range of initiatives to support transition within the community.

As part of its activities over the past 5 years or so, BRCT have made deliberate efforts to collate and disseminate information about energy efficiency, conservation and generation. Increasing energy literacy is an explicit aim of the BRCT, who have offered free energy advice to members of the community, run a series of energy audits, and distributed information via a regular newsletter. There is also a well-known project to establish wind turbines in the area, and all of this has contributed to the energy literacy of the community. Discussions about PV are part of a broader awareness around different aspects of energy. The BRCT also hold meetings and workshops aimed to increase the technological capacity of community members and help reduce the costs of PV installation through participating in the process. An information/training workshop was also held in Waitati to enable local people to become qualified installers.

Additionally, social networks, through which people were learning about PV and energy generally, played a large role in supporting a developing interest in PV and making the journey less daunting. Family, friends and acquaintances were a key information source for many of the Blueskin Bay interviewees, and most were actively sharing their knowledge and discussing PV with family and friends, and in some cases with the wider public, interest groups or even commercial entities. Through workshops and other community events, members of the community were able to share their information with others, and they (and the BRCT) were regularly cited as the first 'port of call' when people a question about PV.

> *"I'd still be thinking about [installing PV]. But it's definitely made it more accessible to get some information, because you know someone just down the road is focusing on it, and there's been quite a pool of people. So, it's definitely made it more accessible to try and get the information, and know that they're into it around here, and that it obviously can be done and that it works quite well. So that's probably helped a bit I think."*
>
> Mary, 45-54 years, homeowner

The information provided or facilitated by the BRCT served to simplify options for households, meaning that they still had choice, but did not need to undertake extensive or complicated research themselves. Exhibitions and meetings run by the BRCT also acted to demystify some of the processes. The kind of information provided by the BRCT is not necessarily easy to access elsewhere. The BRCT also, importantly, made people aware of the costs involved, filling an information gap. So rather than residents assuming PV was unaffordable, they were presented with the reality of how much it would all cost.

A bulk purchase scheme helped reduce costs for the community further:

> *"The economies of scale are the bulk purchase of PV panels. And having a project manager who sourced the inverters from Australia, from bankrupt solar install businesses. Completely compliant, new gear but … sales in Australia, [means that it's the] same gear that's available in NZ but at a third of the cost."*
>
> Mark, community energy expert

Although the BRCT was not itself actively involved in financing or delivering PV installations, it provided a niche environment that shielded, nurtured, and empowered the uptake of PV (Smith and Raven, 2012). Competencies and skills were developed through information sharing processes such as the community based training and information workshops, which led to further increase in solar literacy and expertise within the community as well as practical assistance with installation. Positive experiences were also stimulated through the increasing ubiquity of the panels and the influence of knowledgeable friends and neighbours passing on information. Cost barriers were addressed through information provided by BRCT and residents were made aware two installation options, both of which could make the installation of PV more affordable and further empower uptake: bulk purchase of panels, or a special arrangement with local supplier/installers.

Within the Blueskin Bay area community activities have both directly and indirectly contributed a great deal to facilitate awareness, affordability and ease of installation. These actions are growing Blueskin Bay's social and resource network, as well as enabling the BRCT's vision of a more resilient community to take a sharper focus.

5.4 Niche Business Propositions Facilitating Change

A second area where we are starting to see traction in moving PV technology from niche to mainstream is in the new business propositions and cost structures for distributed energy resources. Traditionally, households adopt PV under a model by which they pay (upfront) for the panels and installation, and consequently own both the system and the electrical power it produces. While some households see this as an investment, with PV adding to the value of their home, it remains largely prohibitive for those in lower income brackets. However other models exist internationally and are starting to emerge in New Zealand.

One such structure is based on a lease system, whereby participants pay a small up-front fee to lease a PV system and battery bank, and then pay a monthly fee to cover the power they consume. Another is based on a power purchase agreement; panels are installed for free, and householders enter into a 20-year fixed price contract for the power they generate at a rate lower than national power prices. Data collected from our choice modelling experiment indicate that these types of cost structures could be successful. During the online experiment, participants were provided with pairwise combinations of the attributes detailed in Table 1.

Table 1: Attributes of PV investigated in the choice modelling experiment

Attribute	Baseline	Level 1	Level 2
Upfront cost	$4000	$8000	$16000
Level of grid independence	Completed disconnected	Disconnected most days each year	Disconnected a few days each year
Payback period	5 years	10 years	15 years
Ownership of system	Owned by customer	Leased from electricity company	Owned by electricity company
Aesthetics of panels	Small and discrete	-	Big and highly visible

Participants were asked to respond to a series of questions to gauge whether they would prefer a PV system that, for example, only cost $4000 upfront but was owned by the electricity company, or one that cost $16000 upfront but was owned by them. Participants could select a preference for either option, or could state that the options were equally preferable. Repeating this with different pairwise combinations of attributes enabled participant preferences to be identified. The results suggest that the upfront cost of the system, payback period, and grid dependence are relatively more important than ownership, which is relatively more important than aesthetics.

These findings suggest that "solar as a service" and other innovative business models that alleviate upfront cost, remove or reduce payback period, and support households become more grid independent, could empower uptake in New Zealand for homes who would otherwise not be able to consider PV. Anecdotally it appears that the power purchase agreement model has been well received in New Zealand, but data is not yet available.

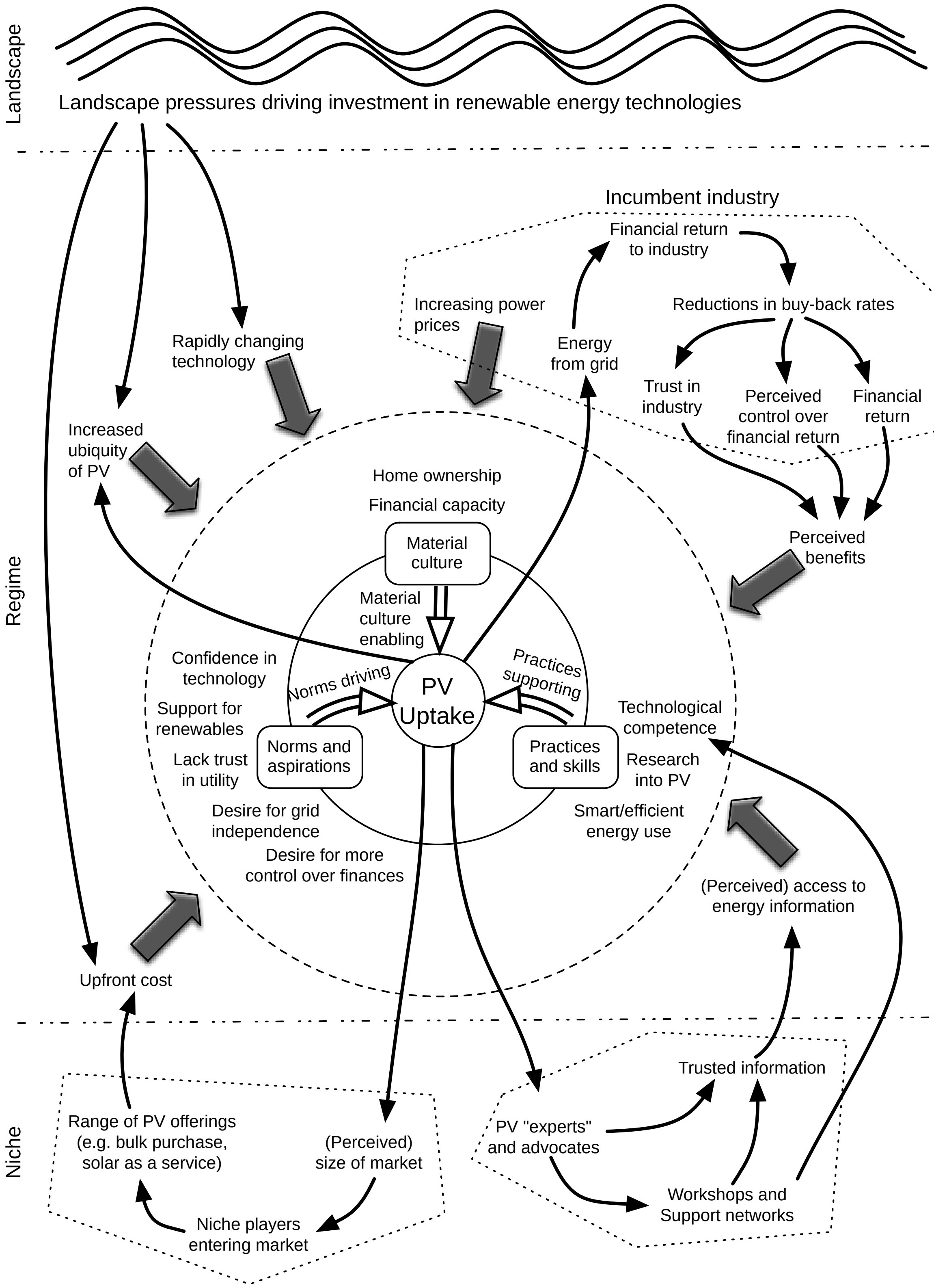
6 Discussion

6.1 Toward an Integrated Approach

An integrated approach brings together perspectives from the energy culture of system actors with interactions between landscape pressures, niche contexts, and the incumbent regime, to provide a deeper understanding of how transition is emerging in contexts where end-users are empowered to affect what has traditionally been a system dominated by incumbents. In this case study of prosumers in New Zealand, we see how the prevailing socio-technical regime, characterised by powerful electricity industry actors, has led to a lack of trust and desire for independence on the part of consumers. This misalignment between the traditional electricity regime and practices, and consumers' values and aspirations for both grid and financial freedom, creates a tension that both landscape pressures and niche developments interact with.

By applying both the EC and MLP lenses to explore the rise of prosumers in New Zealand, we can identify some of the key intersections between the two, and identify the points through which transition is being promoted and constrained. This is depicted in Figure 6, which shows how niche contexts are stimulating behaviour change through supporting existing drivers of uptake and addressing key barriers that have been constraining growth of PV. It also illustrates the interactions between those adopting PV and industry incumbents, who have been affected by and are now trying to impact upon PV uptake occurring at the grassroots level. This integrating perspective extends insight provided by either the MLP or energy cultures frameworks in isolation, and helps provide those key insights into how the existing regime constrains and shapes energy culture, and how various contextual enablers (across the landscape, niche, and regime) can drive and enable a shift in energy culture.

Figure 6: An MLP/Energy Culture reflection on socio-technical transitions



While it isn't yet totally clear what impact the shifting energy culture may have on the wider regime, it is clear that cracks are starting to emerge as incumbents take measures to constrain uptake, which appear to only be feeding a stronger desire for independence. While this provides a good first step to exploring transition emerging from grassroots action, it also brings to light a number of additional questions, which could benefit from further analysis.

This work examined energy culture shifts in the context of technology acquisition, but the interrelationship between material culture, norms, and practices suggests that further behavioural changes may follow. This could be additionally impacted upon by changes in electricity retail offerings – for example, time of use tariffs – and such interactions and impacts on electricity systems would benefit from further examination. It is also becoming clear that whole communities of prosumers are emerging globally, and these may have wider reaching impacts on prevailing electricity systems. The analytical framework proposed here would be well suited to explore such energy culture changes, which are contextualised within both global and national landscapes, transitioning regimes, and the continued emergence of niche technologies (such as storage and peer-to-peer trading platforms).

6.2 Policy and Market Implications

Although the traditional electricity regime remains dominant in New Zealand, actions of niche change agents and emerging business models, along with decreasing prices of PV and storage technologies, are starting to challenge it. Coupled with householders' widespread lack of trust in retailers and desire for grid independence, this suggests that PV installations will continue to grow despite the absence of subsidies, and may break through into the wider regime.

Engineering practices and regulations for managing the electricity networks may have to change to accommodate inflows of power from points where traditionally power has only been drawn. Greater volumes of distributed generation also challenges traditional needs for power generation; less centralised generation may be needed at the middle of the day when solar production is high, and additional generation or inter-seasonal storage may be required to attend to the mismatch between the time of year when solar power is producing the most energy (summer) and the time of year when demand is highest (winter).

Prevailing electricity markets are ill suited to this new paradigm; they were designed for systems dominated by fossil-fuel technologies with significant operating costs, and they fail to effectively incentivise dispatch of low carbon technologies which have negligible running costs. They also fail to send appropriate signals for investment in new capacity, a challenge which is compounded by the emergence of storage technologies and demand side flexibility offerings that can support the integration of solar PV.

Furthermore, existing retail structures are similarly ill matched with future challenges, treating households and businesses as passive consumers rather than the actively engaged owners and operators of distributed energy resources they are becoming. The incumbent response, which, since the research presented here was conducted, has seen a proposed "solar tax" introduction that could serve to further promote end-users' off-grid aspirations. While being off-grid may be beyond the means of individual households, decreasing storage costs alongside emerging niche propositions around peer-to-peer community scale action could make this a reality for many users. However, moves like this could have social equity consequences, and this trend away from centralised provision of power toward distributed resources could cause issues for countries wanting to ensure that electricity grids continue to provide affordable and reliable power to all consumers. Ensuring that nations are able to keep the lights on for all homes and businesses (and not just those who can afford their own PV) may require a rethink of the entire electricity market structure.

6.3 Conclusions

New Zealand's current transition is being facilitated by PV advocates in pockets of the general population, and solar retailers offering services to consumers that overcome the main barrier of upfront cost. However, we have seen some forward-looking companies start to enter in this space. By embracing PV and associated technologies (e.g. storage systems) rather than trying to constrain uptake, they are modifying their business opportunities to allow them to play in a distributed energy future; through owning and controlling the power flows from micro-generation within their networks they are in a better place to manage assets in light of the rapidly increasing uptake of PV.

By exploring the interactions between the energy culture of adopters of niche technologies, emerging business models, and the incumbent industry, we can see how the different intersections and feedback loops can act as levers for change. For example, increasing numbers of PV installations and installations with storage have a net negative impact on the amount of energy purchased from the electricity grid, which impacts on the revenue streams of generation, retail and distribution companies. To date this has caused the industry to take actions (e.g. dropping buy-back rates for purchasing power) that impact negatively on the financial return for consumers with PV, and further erodes trust in the industry. This may create another feedback loop that serves to increase both the number of consumers considering installing PV, as well as driving smarter use of energy to maximise on-site consumption of the energy produced, further driving down energy purchased from the grid.

This observation highlights the importance of exploring the interactions between industry, policymakers, change agents and consumers, and allows mechanisms for stabilisation and disruption to be explored in greater detail. Understanding the energy culture surrounding early adopters and niche innovators enables us to explore how the current socio-technical regime, and responses from the incumbents, is driving or constraining momentum around widespread transformation.

Although this particular work focuses on PV uptake in New Zealand, the framing we propose can be applied to other transitions occurring in other parts of the world. Indeed, the theoretical underpinnings - the MLP (Geels, 2002; 2004) and the Energy Cultures Framework (Stephenson et al., 2010; 2015) - have been used to study a variety of socio-technical transitions across a range of users, technologies and contexts. We hope the conceptual framing we provide in this work can be useful to researchers, practitioners and policymakers, providing valuable insights as to how policy interventions might promote or constrain adoption, and the implications for ensuing social and technical transitions in the energy sector.

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