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The socio-technical regime networks associated with the implementation of direct current (DC) electricity in the built environment

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Abstract:

The use of direct current voltage in the built environment has a number of potential advantages. However, implementing DC voltage is not just a technical challenge; there are also many human interactions with the technical system that will be affected by such a change. This paper seeks to show how socio-technical systems theory can be used to characterise the different elements that affect the implementation of DC in the built environment. By presenting an initial mapping of the socio-technical system around electricity supply for the built environment, this paper identifies the actors, networks and institutions, and associated rules and regulations that constitute the regime networks that are associated with the electrical system in the UK. It has shown that some actors can function in more than one regime network and presents some of the interrelationships between the different network actors, all in a framework of increasing influence on the decision making process to implement DC voltage electricity.

Keywords:

Alternating and direct current voltage, the built environment, socio-technical systems theory, socio-technical systems theory, niche innovations

1.0 Introduction

At this time the supply of electricity to the built environment is in the form of alternating current (AC) voltage and has been since the race between Edison and Westinghouse was won by AC voltage. For some of the history see Kinn (2011 pp. 11-12.). However for some specialised loads, DC voltage is still in use. For example it was only in 2007 that the last DC supply line was cut by the conEddison company in New York, after which the DC loads were supplied from the AC network via a transformer (Lowenstein, 2008). Since the advent of the silicone chip and the development of power electronics (Meindl, 1997), the loads using electricity have developed from purely electrical to electronic applications. This means that more and more loads actually consume DC electricity, even though they are supplied by AC. This is either via an external (black) power adapter, or where internal AC-to-DC transformers are used, it is situated somewhere in the appliance and can be found where the casing feels hotter. Transformers are lossy and depending on their design and cost, operate at efficiencies of between 25% and 90%. (Calwell & Reeder, 2002:

4). An important niche environment where DC appliances are used is in the leisure industry where the electrical supply is from 12V (car) batteries. However the range of products available while increasing, is limited (RoadPro, 2013) compared to the amount of off-the-shelf AC powered household appliances.

1.1 Advantages of DC voltage

If DC electricity is used as the sole means of electrical supply then there will be the advantage of the elimination of the ubiquitous AC transformer's in each appliance, which can be up to 25 per household (Calwell & Reeder, 2002, p.7) and when micro-generators are used, the need for an expensive inverter is eliminated. Their elimination reduces the amount of energy lost in multiple conversions and therefore for a given peak load requirement, smaller DC micro generators will be needed, and therefore the cost for the system will be smaller (M.C. Kinn, 2011, p.109). Or for the same outlay a larger DC micro-generation system can be installed thus increasing the energy supply. DC electrical applications have less parts then their AC equivalence, therefore their mean-time-to-failure is lower, and in operation DC motors, fans, compressors, etc. are much quieter (M.C. Kinn, 2011, pp.113-114). By eliminating transformers, and increasing their mean-time-to-failure, their life cycle carbon footprint should be smaller than that of an AC equivalent application. Another advantage of DC only appliances is, their physical size is smaller and therefore the amount of materials needed to manufacture them is less. Although all this is logical and claimed my manufacturers, to prove this academically further work is needed. One only has to look at the iterations of the mobile phone over the last thirty years to see how power electronics and battery size has miniaturised. One very important outcome of the technical transition to DC voltage will be to provide the best level of energy independence with security available.

1.2 Technical limitations at this time

The main technical limitation of using DC electricity is the operating voltage. Extra-low-voltage, which is that below 50 Volts (BSI, 2008 -2011) suffers from voltage drop issues, whereas low-voltage applications up to 400 V DC suffer from unique safety issues (M.C. Kinn, 2011 Chapter 5).

1.3 Methodology

For this research the starting reference is the existing technical components of a grid connected AC voltage system. Changing the electrical system from AC to DC or just making the decision to use DC instead of AC as a means to provide electricity to the 1.4 Billion people (G.E.A & IIASA, 2012: xv) who are not yet connected to the grid, has far reaching consequences beyond the actual technical changes to the electrical system itself. Each DC component will have to be designed and manufactured to a specific specification, installed by an accredited installer, and used in a safe manor. All this has to operate in a highly regulated environment.

There are many interactions between people and the technology throughout the life cycle of the electricity system, these interactions will be affected by the decision to use DC voltage. Therefore DC voltage not only changes the *technical system* but it will also have consequential effects on *people*; from policy makers, to manufactures/installers to end users, as well as on the *rules* and *regulations* that surround decision making, installation, maintenance and the end use. There is also the effect this will have on *societal goals***,** like carbon footprint, energy independence with security, fuel poverty, resilience of supply and sustainability, see section 2 of Summary for Policymakers, (G.E.A & IIASA, 2012, p.35.). Therefore the system in which the DC voltage is to be implemented has to be looked at in a wider context as a Socio-Technical system, where the importance of who is affected and how they are affected, together with the technical system, will all have to be taken into consideration.

The aim of this paper is to use socio-technical theory to identify the different regime networks and how they interact with each other. In section 2 we will look at socio-technical theory in general and in section 3 we will look at the different networks of people who will be affected by the changeover and some of the interactions between the networks will be presented. The significance of this research is discussed in section 4, and the conclusion and further work are in Section 5

2.0 Socio-technical systems theory

2.1 Introduction

Understanding how changes in coalmining affected the coalminers (Trist, 1951) was a seminal work in understanding Socio-technical transition theory, which has since been used to understand transitions from sails to steam in ships (F. W. Geels, 2002), from a high to a low carbon electricity system (Foxon, Hammond, & Pearson, 2010), changes in the Dutch electricity system (Verbong & Geels, 2007), and now for the transition from AC to DC voltage in the built environment.

The socio-technical theory used in this paper is based on the many academic papers put out by Professor Frank W. Geels and looks at the electrical system in the built environment through the eyes of his multi-level perspective (MLP) (F. W. Geels, 2002). In general our electrical system exists in the socio-technical model on three levels, the *landscape*, the *regimes* and the *niches* Fig 1. The landscape provides the influences that put pressure from ‘above’ on the actors who operate in the regime level and the niches are innovations that have identified existing, or who want to open new, ‘windows of opportunity’ to change aspects of the regime that will enable change to the landscape.

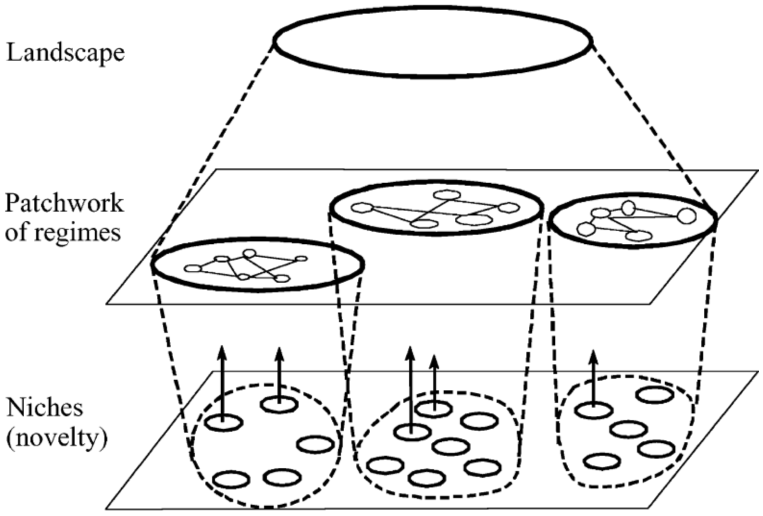

Fig 1 Multiple levels as a nested hierarchy.

2.2 The Socio-technical Landscape

The electricity market exists in a mature production and distribution system stabilised by many locked-in mechanisms, where continuity of supply is taken for granted by most consumers. However *continuity of energy supply* is in fact a landscape pressure and is dependent on landscape activities such as; a continuing availability of fossil fuels, supply chain resilience to sudden changes like natural disasters, terrorism or war and consumer ability to pay for the electricity without being in "fuel poverty".

The different methods of producing electricity and the amount consumed, provides its own landscape pressures. The terminology in use is the lifecycle-carbon-footprint associated with consumption and its consequential effect on *climate change***.** Therefore continuity of energy supply and climate change are two main landscape pressures placed on the producers and consumers of electricity. The solution required to alleviate these pressures is for the electrical system to provide energy security with independence in a sustainable way. This can be achieved with what is known as a decentralised, or as sometimes called a distributed energy generation system (Patwardhan et al., 2012, p.1187.)

2.3 The Socio-technical Regime Networks

The socio-technical regime comprises different networks, each of which has its unique set of actors (people) who operate within one or more networks, and who have many interactions with members of other networks who rely on their output to make decisions. All the actors in the regime networks work to keep the system dynamically stable. We have identified six regime networks associated with the use of electricity in the built environment. We start with the *technical system* which is passive, and continue with the *user* and *supplier* networks, which are usually very benign, but have a limited input into the decisions about using DC. Then the *research*, *standards* and *societal-groups* networks which are intricately involved in supplying the research and providing the written information needed by the *policy* network, who are the decision makers who will be legislating and regulating the new DC voltage system.

2.4 The Niche Innovations

This is the innovative change/s that is/are being initiated to the technical system to alleviate the pressure from the landscape. This research is employing the niche innovation that the supply and consumption of the electricity in the built environment should be in the form of DC voltage. For the regime actors to be willing and able to implement this niche innovation they must be convinced that the change will alleviate the existing landscape pressures. The process through which a niche innovation will go is explained by Geels and is illustrated in his Fig 1 (Frank W. Geels & Schot, 2007).

3.0 The actor networks in the socio-technical regime

3.1 Introduction

The electrical system is by definition technical; however there are many direct human interactions with the actual system, as well as those who are involved in all the decisions made for its safe implementation. We have therefore identified several different regime networks in the meso level of MLP model. Starting with the technical system, and those who are directly connected with it, and then working our way through the standards and research networks until we will finally come to the decision makers. These different regime networks cannot be looked at in isolation. Just as there will be interactions between the different actors in a single network, there will also be interactions between actors in different networks. These multiple connections form a web of interactions that can be quite complicated. In Fig 2 we have listed the different regime networks in the order of their ability to influence the decision to implement DC voltage.

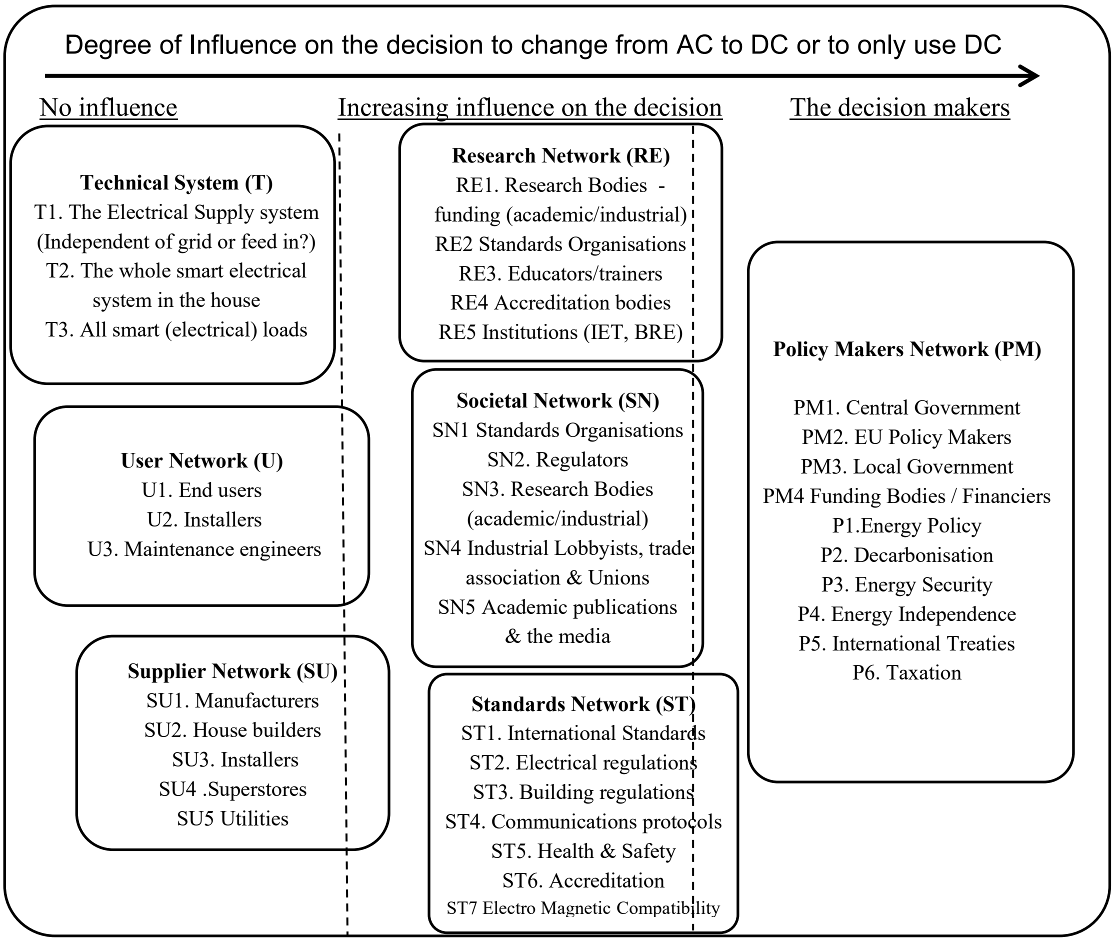

Fig. 2 The regime actors in the socio-technical electricity system

3.2 The technical system (T)

In general the AC electrical system in the built environment is a fully locked-in functional passive system which can be split up into three components, the electrical supply, the electrical mains system, and the loads. As a physical installation, the technical system will be wholly within the “no influence” category of our model.

(1)The electrical supply system

At this time the AC electrical supply coming into a home is via a 100A cable that connects to the multiplexer board via the (smart) meter. With a hybrid system there will still be an AC grid connection, which will be the backup system and a micro-generation system that will provide the DC supply. For the DC only system, besides the micro-generators and voltage regulator, there will be a backup storage system. (The type of generators and backup system that could be used is beyond the scope of this paper)

(2)The electrical mains system

In an AC system there is $2.5mm^2$ wiring for the power sockets and $1.5mm^2$ wiring for the lighting system. All wiring starts at the multiplexer board and terminates at the power or light sockets. For extra low voltage DC electricity, a new set of larger cables of $4mm^2$ and $6mm^2$ will need to be installed (M.C. Kinn, 2011, para. 5.4.1). (The system voltage for DC electricity in the built environment is not yet defined and is beyond the scope of this paper)

The smartness of the DC system is not only in its’ ability to do smart things like control lighting, open and close curtains or remotely control devices, (Aldrich & Harper, 2003), the control system will also be able to act like a smart grid whereby it will be monitoring the voltages and currents and making many autonomous decisions about how energy is used. The control system will consist of a CPU, a mobile phone interface (Liu et al., 2005), communications channels and embedded electronics in every place that an activity will be monitored. This will mean that all switches, and wall and light sockets will be replaced with those that have smart embedded electronics. In essence, this system will be a Home Area Network (DECC, 2012). It is envisioned that there will not be any need for a set of data cables as the control system will employ a power line communications protocol. (Moshe C. Kinn, 2011)

(3) The loads

Traditionally electrical loads operated on purely AC voltage, however today almost all of AC loads have electronics incorporated in them for control, monitoring or interface purposes, which are supplied with DC voltage via an internal AC-to-DC converter. In the DC environment there will be no AC loads, all motors, compressors etc. will be DC, with an embedded chip-set and software that will allow for interaction with the control system. At this time there are a few competing/complimentary smart-house electronic technologies each with its own set of protocols, (HD-PLC; HomePlug; HomePNA; KNX; Zigbee). From the electrical engineering point of view the traditional interface between the load and the power supply, the plug, will change from its traditional shape to one of much smaller size with two or three contacts depending if earthing is needed.

The technical transition from an AC electrical system to a DC system will see many changes to the components in the technical regime. All these changes will affect other regime actors, such that a web of regime network interfaces will take place. Understanding all the multifaceted interactions that presently exist in the socio-technical electrical system, is key to understanding; to what extent AC electricity is locked-in (Allen, Hammond, & McManus, 2008; Unruh, 2000, 2002), what transition pathways will exist to facilitate the transition from AC to DC (Patwardhan et al., 2012; Verbong & Geels, 2007), or in the case of those not yet connected, from the present lock-ins to the implementation of a DC system.

3.3 Users network (U)

The label "Users" is used very loosely, as besides the consumers, users will also include the electricians/technicians that install the system and the engineers that maintain it. Todays' AC system is passive, and the maximum that is required is changing light bulbs and occasionally resetting the circuit breaker. However in the smart DC environment, depending on the system specification there may be a higher level of interaction between the users and the technical system for which training will be needed. Traditional system designers and installers will need to be retrained to understand the new electronic environment and be reaccredited to maintain a high standard of workmanship. New skills that include computer control and communication networks that are not associated with traditional AC systems will be needed. All this will be provided by the research and standards networks.

Users are individuals and have very little influence on the decision making process with regard to the use of DC, but are affected by the decision to do so. However as an organised group they can raise awareness of things that affect them and place pressure on the decision makers, using the societal network discussed below. They therefore have been placed slightly into the increasing influence category.

3.4 The Supplier Network (SU)

The hardware and loads in the new smart DC environment will be radically different than those in the traditional passive AC environment and will have to conform to the constraints put on them from the standards, research and societal networks. Although at this time some DC hardware and loads do exist, much will have to be re-engineered or adapted for the full DC environment to come to fruition. For the provision of DC supplies, the whole supply chain will have to work together. In a sense, there is a chicken and egg scenario, property developers will only specify a DC system if it is available in the market to buy, while manufacturers will only make and retailers will only stock, products that sell. Therefore for DC to become a strong force in the built environment, a market mover or catalyst will be needed that could provide the demand that will drive the supply. The development of energy service companies is another strong way to further the proliferation of DC. The supplier network is usually constrained by the standards regime and the laws and regulations under which it must operate, as well as market influences. In a free market, policy makers need those in the supplier network who are able to be market makers/movers to take up their decision and implement DC. This gives them somewhat a limited influence, we have therefore placed them more into the increasing influence domain.

3.5 The Standards network (ST)

Electricity by its nature can be harmful to both humans and to other hardware connected to the network. Therefore in the built environment there exists, Statutes, regulations, internationally/nationally recognised Standards, protocols and recommendations, to maintain high standards of manufacture, installation, operation and health & safety. Therefore changing from AC to DC will require a change in the whole regulatory environment that encapsulates the use of electricity in the built environment, a change that will affect many of the other regime networks. To be able to redraft or amend the current documentation the technocrats responsible will need to be informed by the research network about all aspects of how DC will affect the way electricity is used. Through the production of Standards this network is one of the most influential networks in the entire socio-technical regime. These Standards are not only the body/basis of many policy decisions, but actors in this regime also operate within the policy regime, thus this network overlaps into the decision making domain.

A comprehensive list of statutory regulations and associated memoranda that exist for installations in the AC electrical environment can be found in Appendix 2 of BS 7671:2008 2011 (page 292). For installations in the DC environment many, if not all of them will need some sort of additions and amendments. Other regulations that will need to be looked at are the building regulations, and retraining and accrediting installers.

For power line communications protocols in a smart DC environment, there are different international standards depending on the speed of data transfer, the modulation technique used, the frequency at which the system operates and the bandwidth used, to name but a few. (Kinn, 2011b Section VI).

Some of the UK Statutes and regulations that will be effected:

1. Requirements for electrical Installations IET Wiring Regulations BS 7671:2008 2011
2. Electrical Safety, Quality and Continuity regulations 2002 as amended.
3. Electricity at Work Regulations 1989 (SI 1989 No 635)
4. Electrical Equipment Safety Regulations1994 (SI 1994 No 3260)
5. The Plug and Sockets etc. (safety) Regulations 1994 (SI 1994 No 1768) - made under the Consumer Safety Act 1978.
6. The electromagnetic Compatibility Regulations 2005 (SI 2005 No 281)

3.6 The Research Network (RE)

(1) Introduction

Technical input will be needed over the while lifecycle of the electrical system. The research regime can be split into three streams; the first is the electrical system specification, the second is the re-engineered/ adapted AC system components, and the third is the correct and safe installation, maintenance and usage of the system. The process starts by research to characterise the existing AC system and the proposed DC system. Then to look at which changes will be needed in the whole socio-technical environment so that we can understand how DC can be implemented in a safe and sustainable manner. This is only the framework for the physical aspects, then there is the process to change standards, regulations, and working practices which involve technocrats doing research and forming working committees to draft new documentation.

(2) The electrical specification

Foremost what is needed is research to establish a new voltage and current rating for the DC environment. This has to be set such that the power ratings of the DC loads are optimised and system energy losses are minimised. Extra low voltage DC systems suffer from voltage drop and ultimately system failure, therefore such systems will need a specific control mechanism. In the build environment low voltage DC of between 300 to 400 volts do not usually suffer from voltage drops but they have their unique problems including the size of the electrical system components needed to deal with electrical arching and earthing hazards.

(3) DC components and loads

In the all DC environment all loads will have to be converted to run on DC voltage. The work that those in the research regime will have to do will be the reengineering, redesigning, and testing of new prototype DC loads. They will also need to compare and contrast energy consumption, carbon footprint, and life-cycle of comparable AC and DC gadgetry to prove or disprove if DC gadgetry can be more sustainable than AC equivalents. Their goal will be to make DC gadgetry operate with the same ease as AC equivalents but be designed so that their power consumption is optimised. This work will be invaluable in the process of DC development.

The actors in the research network will have multiple interactions with every other regime network. They will have to characterise and specify the technical aspects and see how they will affect the user and standards networks. From the point of view of installation, they must provide information and education to the policy, user and supplier networks, often via the societal network of peers, media, trade associations and educational institutions in their own network. They will have to secure public or private finance via actors in the policy network. They are therefore placed in the increasing influence category. However, as in many cases, what they produce will be decisions that the decision-makers rubber stamp, and as many of them will be technocrats operating in the policy regime, we have placed them overlapping into the decision makers category.

3.7 Societal networks (SN)

The proliferation of DC will bring profound changes to many people. There are many industrial, trade and professional associations, unions, and the media all of whom seek to defend their members or agendas in one way or another. They will have to be informed and consulted with, if their members have to change any working practices. Most of these network actors influence the decision makers by way of public pressure. We have therefore overlapped this network into the “decision makers” domain.

3.8 The Policy Makers network (PM)

Those in this network have the power to make the decisions that govern the way we live and develop public policy to fulfil societal needs. They are therefore the ones with whom the decision to use DC voltage in the built environment lays. Decisions made whether statutory or regulatory, will be based on information received from many other regime networks. These decisions are written down in Acts of Parliament, regulations, policy documents, and standards. The ultimate arbiter as to the public financing of research is the Chancellor of the Exchequer who sets the overall UK research budget, however the decision makers as to direct funding of a DC voltage project would be through the research network.

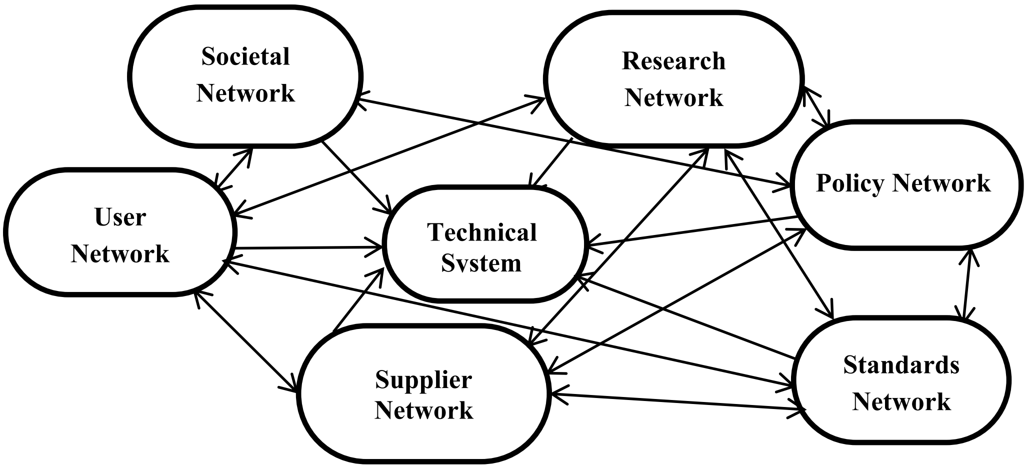

Fig 3. The web of interactions between the regime networks

4.0 Discussion

Of the three components in the transition from AC to DC electricity that have been laid down by Foxon et al (2010, p.1205.), this paper has endeavoured to characterised the existing regimes in the electrical system, and has identified a niche innovation as the change from the use of AC to DC electricity. The third component, to specify the transition pathways, has been left for future work. The preceding analysis has revealed the complexity of the socio-technical system that surrounds the generation, distribution and use of electricity in the home. It illustrates well that technical solutions will not only be required to produce improved technical performance, but will also need to fit within or reshape a whole variety of regime networks. By illustrating the context of the electrical system in this way we can gain a rich understanding of the current situation.

What we have also found is that regime actors are not exclusively associated with specific networks, many actors have a role to play in different regimes. This duality of role should help bridge the gap between different networks, and towards breaking down barriers to the present locked-in system. It has been found that there are universal landscape pressures in the energy system. However, different policy regimes in different parts of the world may put more emphasis on some, which therefore produces different energy policy in different countries. This in turn will dictate that the transition pathway in one country may be different than that in another. It is therefore hoped that the analysis in this paper can be useful in helping to answer questions such as: What other types of niche innovations might fit easily into the current system? For particular niche innovations, what changes to the regime and/or landscape might be necessary for the innovation to take hold? In which international contexts might a particular innovation have the best chance of taking hold?

5.0 Conclusions and further work

This research has shown that characterising the electrical system in the built environment by using socio-technical systems theory, shows the complexity of both the social and technical aspects of the system and the consequent difficulties in making changes. It has also shown the web of different actor interactions (Fig 3) that are associated with changing from AC to DC, many of whom have no direct connection with the physical change, but are outside facilitators and some have their own agendas. These agendas coupled with a locked-in AC system will act as barriers to the change. It has also shown that some network actors can function in more than one regime network. This analysis also allows us to do further research that will look at possible transition pathways that will remove barriers and break-out from the AC system lock-in, to the development and proliferation of new DC systems.

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