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Energy and Mobility in Smart Cities

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in all modern cars, provides for efficient fuel injection and monitors vehicle systems for faults. The power and sophistication of on-vehicle electronics have developed rapidly over recent decades, and these systems increasingly started to involve aspects of driving itself, starting with cruise control systems and, later, parking assist technologies. Today we see lane-assist technologies, adaptive cruise control and fully automated parking. These developments have combined with innovations coming out of the Cold War associated with global positioning and digital mapping – what today in the UK is termed 'sat nav'. For an excellent overview of future UK possibilities in mobility, we recommend the Rand Europe report *Travel in Britain in 2035* (Rohr *et al.*, 2016). The various developments, combined with the emergence of low-cost sensors, place us on the cusp of achieving the fully autonomous driverless car. The journey to such a technology has been a long and incremental one. In summary, we see technologies converging: first the electric vehicle (EV), referring to the electric power train seen in vehicles such as those produced by Tesla Motors, but also including other concepts such as plug-in hybrids or even hydrogen fuel cell EVs; and second the use of IT in vehicle control as in the 'autonomous vehicle'. We suggest that the two innovations will one day be seen to be two sides of the same coin that will be associated with the most significant evolution in mobility since the advent of the true family car 100 years ago, but the impacts will not simply be restricted to the domain of mobility – they will be seen in energy as well, and most especially in electricity.

2.3. New mobility and the implications for the electricity system

In the UK the electricity distribution company Western Power Distribution (WPD) has been examining the future of power distribution in the face of changing expectations including issues arising from the electrification of mobility. Its study, known as Electric Nation, is uncovering some interesting insights (WPD, 2017). The project is ongoing, but it has already revealed that (in 2018) smartphone apps allowing customer interaction with smart charging systems (i.e. those that manage EV charging while protecting electricity networks from excessive loads) are seen as important to customers – but they must be relatively simple and easy to use. Two app-based systems having been tested.

There are indications that 25% of EV drivers charge their vehicle in the late evening using a timer (Storer, 2018). The Energy Nation team expects that some of these timer users might be accessing the very long-standing UK off-peak tariff known as Economy 7 (originally introduced in 1978 for night time electric storage heaters). If this is occurring it cannot explain the whole 25% figure noted above. Electric Nation notes that there are many customers without a dual tariff (e.g. Economy 7) making use of timers so as to charge at night. It seems likely that this is a result of well-informed users keen to shift their charging to a time of low system demand even in the absence of any incentives on them so to do. As such, these individuals are using timers because of a relatively sophisticated understanding of the system issues coupled with a desire to do the right thing.

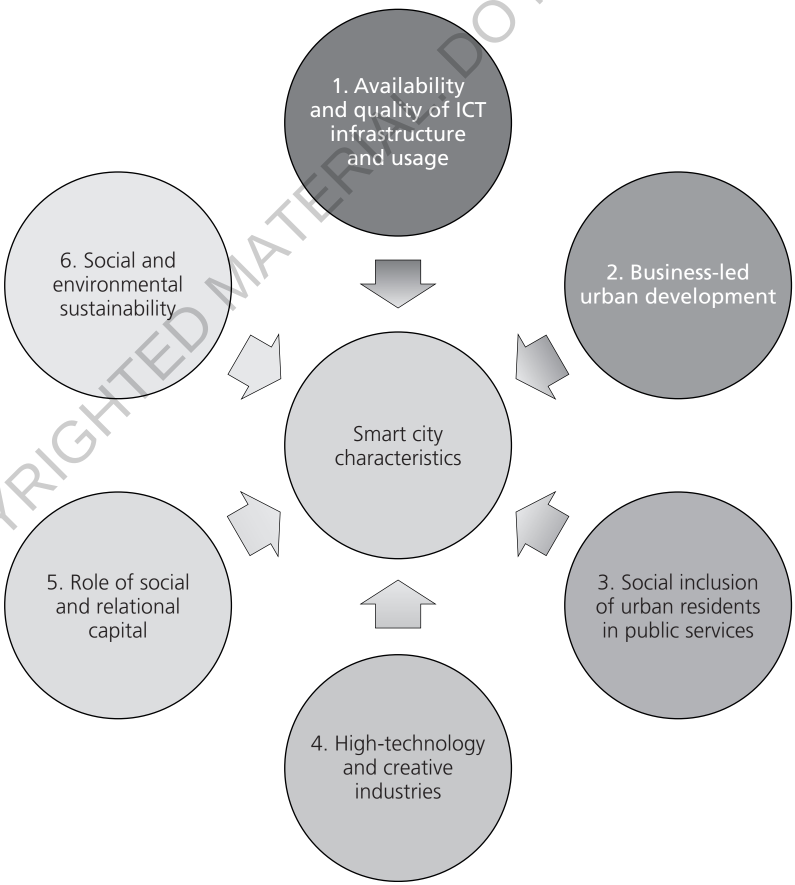
UK innovations extend into the retail supply of electricity with the introduction by one small entrant energy supplier, Octopus Energy, of an 'agile tariff', which permits low-cost energy use if congested (early evening peak) times are avoided by consumers. The

A Smart City is an agglomerated area affected by a high concentration of learning and innovation as a result of creative citizens and institutions as well as the implementation of a digital infrastructure with the overall objective of achieving economic growth and a high quality of life, while keeping in mind the scarcity of natural resources.

(Richter *et al.*, 2015, p. 214).

In an attempt to synthesise the approaches taken towards understanding smart cities, Richter *et al.* (2015) highlighted six characteristics of smart cities, shown in Figure 3.2. ICT is frequently considered the most important characteristic, providing the essential communication and infrastructure needed for 'smart' activity, including the provision of information via digital systems to allow systems to be designed efficiently for consumers and citizens and a platform for innovators to work from, as well as effective city-wide resource management, distribution and recycling, such as sensor systems, cloud technology, energy management and monitoring via smart grids.

Figure 3.2 Six characteristics of smart cities. (Adapted from Richter *et al.*, 2015)



to combine economic, technological and social factors in the definition of an agent gives ABM a useful role in investigating potential policy impact and theory testing.

8.4. Case studies

In this section, a series of case studies where ABM has been used to provide insight into the potential for community energy schemes are briefly described and analysed. Each case study has been selected to illustrate the utility of ABM in analysing a particular facet of transition to a smart city environment. The studies are developed using the CASCADE ABM framework (Rylatt *et al.*, 2013). Lessons from each are drawn together in the discussion section that follows.

8.4.1 Adoption within households

Significant penetration of community energy schemes will require households to adopt new technology and practices. ABM is ideally placed to combine conventional economic understanding of how adoption decisions are made with psychological theory offering insight into other factors that may affect such decisions. The ability for spatial considerations to be integrated into ABM offer the potential to directly model contagion, where observation of others' adoption can influence a potential adopter's decision. The heterogeneous nature of consumers' predisposition towards adopting various technologies or practice can be accommodated, by quantification of the predisposition on a per-agent basis, by assigning predispositions across a population. A representative spread of predispositions can be either estimated or informed by empirical data from surveys or by using a proxy for the predisposition.

The last approach was undertaken in a model designed to investigate the factors influencing the adoption of rooftop PV systems under the UK Feed in Tariff (FiT) (Snape, 2016; Snape *et al.*, 2016) in order to understand the impact of an incentive policy, in this case the UK FiT. In this model, previous work on a framework for pro-environmental behaviours was used to give an indication of the spread of predispositions towards installing renewable energy, in this case rooftop PV systems. This predisposition was incorporated into a decision-making algorithm based on well-tested psychological theory (the social cognitive theory, SCT), which was used to codify the way in which economic, psychological and social factors were combined to inform the decision-making process within an agent (Figure 8.1). Observation of neighbours was included in the model, with the number of neighbours within an agent's immediate locality being used as a factor influencing the perceived social norm associated with PV-system adoption. The ABM algorithm logic and parameters are shown in Table 8.1 and Figure 8.2.

The model in this case was data informed – it was made spatially explicit by integrating the model with GIS information, the model timestep was aligned to a real-time interval (48 model timesteps = 1 day) and real-world statistics on population distribution were employed alongside the pro-environmental frameworks. The specific community tested in this case was urban and geographically bounded – an illustration of the layout of agents, differentiated by their pro-environmental predisposition category is shown in Figure 8.3. Stochasticity was introduced into the agents' behaviour firstly by allowing the time between agent decisions to vary randomly with a mean of 3 months between for scaling – testing a given scheme with vastly differing numbers of participants, or with many schemes running simultaneously without the need for real-world trials.

8.4.3 ABM to scale up an integrated community energy scheme

The final case study demonstrates the utility of ABM when investigating the extent to which a community energy scheme might be scaled up by replication across communities with different demographics. The scheme described is the SWELL scheme, which ran a trial community energy scheme across 50 participating households in Shrivenham and Watchfield (villages in Wiltshire, UK).

Briefly, the scheme aimed to incentivise local use of energy generated by PV systems within the participating community. Not all participating households had PV systems, but all could benefit from subsidised electricity prices if using surplus PV energy as it was generated. For regulatory reasons, the subsidy in this trial was paid as vouchers after the fact, rather than altering the supply contract of participating households. Among the participants, a number had dwellings heated by electrical storage heaters, thus integrating the thermal comfort with electricity demand in a number of households. As part of the trial, these households were fitted with smart heating controls. In addition, a number of houses were fitted with domestic batteries, to test the potential for distributed electricity storage within the scheme. Results from the trial were good, with the scheme showing that no participants lost out by participating in it, while some residents gained significantly – particularly those with electrical heating (Boait *et al.*, 2017). The gains in electrical heating were twofold: firstly, simply through smart controls and information from the community energy scheme improving the use of the storage heaters and thus efficiency; secondly, through the smart controller using energy from local PV installations where possible, thus reducing cost.

The next step for the scheme would naturally be to scale up to implement at larger scale, through introducing the model to other communities. This raises a question regarding the potential efficacy of the scheme in different community contexts. ABM proved useful in this regard within the project, and work continues to widen the scope of modelling to investigate the potential for significant penetration of this community energy scheme. In this case, the ABM was firstly encoded with the payment mechanism used by the scheme, essentially a model where PV energy in any half hour was firstly netted off against the owning household. If there was excess across the community after this process, this was shared in a series of rounds among scheme participants who were consuming at the time. Scheme participants were provided with a smart signal, which indicated times when demand was desirable to use PV-generated energy and times to avoid. This was provided via a web portal to any consumer and to the smart controllers of heating and storage where these were fitted.

A particular scenario for the ABM was then constructed to mimic the real-world scheme and run to validate the set-up of the model. To do this, existing models of PV generation along with the smart signal and control regime within the CASCADE framework were used (for details, see Boait *et al.*, 2013). The agents were configured with PV capacities to match those in the scheme, and also electrical heating to match those in the scheme.

strategies. The European Innovation Partnership on Smart Cities and Communities (EIP-SCC, 2013, p. 16) observed that 'there is presently no single, broadly-accepted indicator framework that reflects the 'smart city' approach'.

There are many city measurement frameworks and indexes available, although few offer specific smart city measurement indicators and metrics. Some examples include the following.

- The Smart City Reference Model conceptualises the work needed for smart city development through several development stages/layers associated with KPIs, and the corresponding innovation policies required to develop connected, instrumented and integrated infrastructure and related capabilities for intelligent services and innovation (Zygiaris, 2013).
- The Smart City Maturity Model measures the maturity phases of smart city development from city 'ad hoc' project planning, where less smart mature cities are characterised by ad hoc smart projects, to the ultimate 'optimised' city-wide city of systems phase, where more smart mature cities have established smart strategies and more smart city-scale developments (Clarke, 2013).
- The European Smart Cities Ranking (ESCR) model (TU Wien, 2015) measures city outcomes against indicators of 'smart governance', 'economy', 'people', 'living', 'environment' and 'mobility' dimensions (Giffinger *et al.*, 2007).
- The Smart City Index Master Indicators (SCIMI) framework similarly measures 'smart government', 'economy', 'people', 'living', 'environment' and 'mobility' dimensions, although is more focused on digital transformation indicators than the ESCR model (Cohen, 2014).
- The Ericsson Networked Society City Index (Ericsson, 2014) measures cities' ICT maturity against indicators of ICT 'infrastructure', 'readiness' and 'usage' across 'economic', 'social' and 'environmental impact' dimensions (Ericsson, 2014).
- IBM's Smarter City Assessment Tool assesses cities' capabilities in terms of instrumentation, interconnection and intelligence (Dirks *et al.*, 2009).
- The Cities of Opportunity Index of Leading Cities measures 'smart', 'quality of life' and 'economic' indicators (PwC, 2016).
- The CITYKeys indicator framework measures smart city project-level success outcomes and city-level indicators, aligned with EU policies across themes of 'people', 'planet', 'prosperity', 'governance' and 'propagation', with the last described as the potential for upscaling and replication of city solutions (Bosch *et al.*, 2017).

9.2.2.2 Quality of measurement

A detailed examination of available smart city frameworks (Caird and Hallett, 2018) identifies a wide range of measurement approaches, indicators and metrics. Essentially, there is no definitive approach to the measurement of smart city outcomes, although approaches may be appraised against criteria of validity, reliability, credibility and utility, as below.

- **Validity.** Do city measurement frameworks and indicators measure what they claim to measure? To be valid, the selected measurement indicators should be