URBAN DECARBONISATION: A MULTI-LEVEL PERSPECTIVE ON ENERGY CONSUMPTION BEHAVIOUR IN SUSTAINABLE SMART CITIES

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Sustainable Smart City (SSC) leverages smart technological innovations to mitigate carbon. However, the technocratic solutions alone won't deliver decarbonisation since it involves the energy consumption of urban actors. The study aims to investigate SSC technology's impact on energy consumption behaviour as a decarbonisation pathway. A systematic literature review was conducted using the Multi-Level Perspectives (MLP) Lens on SSC's socio-technical transition into the established urban regime as an indicator for sustainable transformation. Upon screening, 65 papers were used for thematic analysis that is then synthesised using three MLP socio-criteria for technological transition: LP - learning process, EV - expectations or visions for the innovation and SN - participation of a broader social network. The findings reveal that the disparate complexity of SSC discourse is related to its early phase of innovation status, as evidenced by the highest gap in the SN requirement. Consequently, enabling SSC technology as a pathway towards urban decarbonisation requires it to break through the established urban regime level. To achieve this necessitates more robust policy advocacy that impacts energy consumption behaviours, which would then drive the technological transition in the direction of urban decarbonisation.

Keywords: energy consumption; multi-level perspective; sustainability, smart city

INTRODUCTION

Decarbonisation was identified as a critical step to the Paris Agreement as part of the sustainability pathway (UNFCCC, 2021). Consequently, many cities worldwide are seeking ways to reduce excessive carbon emissions. As a result, Sustainable Smart Cities (SSC) Has become increasingly popular to tackle this problem with its technological innovation (Meijer and Thaens, 2018). At the regional level, the discourse around decarbonisation initiatives focuses on the household sector as a source of significant carbon emissions. In the United Kingdom (UK) Alone, households contribute about half of the national carbon emissions through energy consumption in the home and personal transport choices (DECC, 2013). As Davoudi *et al.,* (2014) Argued, reductions in household energy use could be much more

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significant if improved domestic technologies and products were more rapidly adopted and used effectively.

However, domestic energy conservation may contribute to the "rebound" effect, in which consumers increase their energy consumption after being 'miserly'. The result indicates that reducing energy demand is not simply about developing energy efficiency measures and technologies but also about changing energy consumption behaviour (Davoudi *et al.,* 2014). Consequently, technocratic solutions via SSC for decarbonisation are often challenged by most scholars (Yigitcanlar and Kamruzzaman, 2018). This is because, while SSC emphasises technological interventions to achieve decarbonisation, it cannot effectively do so without also introducing interventions that necessitate behavioural change (Azizi and Thurairajah, 2020).

Therefore, to explore Sustainable Smart Cities (SSC) As a viable decarbonisation pathway, the diffusion of SSC technologies within the household is investigated using the Multi-Level Perspective (MLP) Lens as a socio-technical transition indicator. Socio-technical refers to a particular analytic perspective which works from several basic assumptions and conceptualisation of technology, human action, and social structure interaction (Geels, 2012). Hence, MLP aids in the identification of issues and obstacles addressed in SSC discourse about energy consumption behaviours as decarbonisation concerns and urban system interactions (Kallman and Frickel, 2019). The findings could inform city planners, builders, and smart city designers to facilitate cities' transition to a more sustainable model and support urban decarbonisation efforts.

SSC technology has gained traction as a means of enabling the intelligent use of digital information to provide improved city administration, energy management, education, and transportation in urban areas to meet sustainability goals. Therefore, the development of techno-centric solutions to support low carbon transitions foregrounded the role of SSC technology in achieving a sustainable future (Stripple and Bulkeley, 2019). However, a disparate and varied definition of SSC has complicated the discourse further. The ambiguity caused by the diverse range of descriptions and models has left it open to various interpretations (Alawdah, 2017). As a result, it isn't easy to establish whether SSC delivers decarbonisation solutions or is a techno-centric fantasy to control the effects of environmental challenges by using modern technology.

Further, the literature indicates an insufficient focus on energy consumption behaviour in SSC models as decarbonisation solutions at the local level (Albert and Flournoy, 2010) And even less so in urban technology transition studies (Carvalho, 2015). The research gaps pose a potential for this study to explore the sustainable aspect of SSC, where its sustainability claims are commonly scholarly contested. It achieves this by investigating the extent to which SSC literature addresses the relationship between SSC technology and energy consumption behaviour at the household level based on the Multi-Level Perspective (MLP) Framework. The MLP is a heuristic approach for analysing how major socio-technical shifts occur and how they can be directed towards a more sustainable path (Geels, 2012).

Referring to Figure 1a, MLP conceptualises the complex and nonlinear interactions that occur in urban structures between three analytical levels:

SL - Socio-technical landscape level: the broader context of societal changes as exogenous macro-developments and influence

SR - Socio-technical regime level: a system of practises and rules created by multiple actors such as market, government, culture, and science

NT - Niche level: innovation and technology formulation

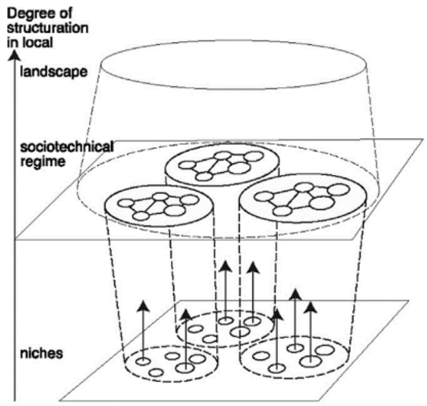


Figure 1a

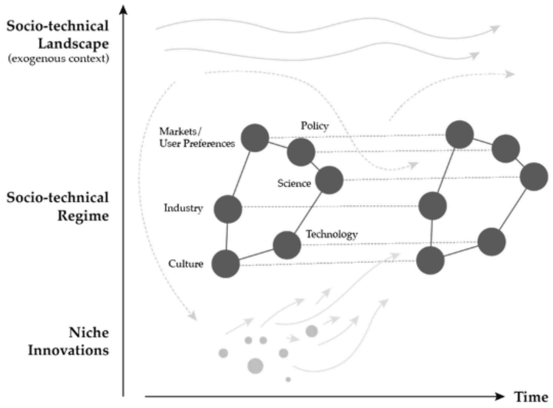


Figure 1b

Figure 1a. A nested hierarchy of the three societal levels in the Multi-Level Perspective. Adapted from Geels (2012)

Figure 1b. The Multi-Level Perspective analysis framework by Geels (2012)

According to Figure 1b, MLP observes technological transition in a city to take place at the niche level where technical experimentation occurs. A bottom-up creative evolution and solutions often result in the technology breaking into the socio-technical regime (SR), thereby transforming the system, and establishing new sustainable pathways (Geels, 2012). Nonetheless, the SR comprises systems of incumbent technology, culture, and social conditions that are hard to break. This level often resists technologies attempting to diffuse into the larger social framework as it often disrupts the established systems. However, regime transformation occurs when the socio-technical landscape level exerts pressure on it and makes it more vulnerable to reform, such as through an urban sustainability agenda, which drives the niche technology to shift the regime in response to urban climatic challenges. Furthermore, MLP asserts that, for SSC transition to occur, it involves unequivocal social acceptance, which demands social support for the SSC technological niches to diffuse within the social-technical regime (Geels, 2012). Therefore, Smith (2012) Proposes a niche analysis based on these indicators to predict a successful technologically driven urban transition to sustainability:

LP: "Learning processes" deal with various dimensions; about imperfections of technology and how they may be overcome, issues of the organisation, market demand, user behaviour, infrastructure requirements, policy instruments and symbolic meanings.

EV: The articulation (and adjustment) Of "expectations or visions", which on the one hand, provide guidance and direction to the internal innovation activities, and on the other hand, aim to attract attention and funding from external actors.

SN: Building "social networks" and enrolling more actors expand the social and resource-based niche innovations.

METHOD

Phase 1: Systematic Literature Review

Socio-technical studies posit that SSC technology requires to successfully transition into the established urban system to have considerable influence on household energy consumption as more users will engage with the technology. A systematic review approach was used to examine this discourse by studying the energy consumption behaviours addressed in the SSC literature. Then the MLP lens was used to synthesise the findings in the second phase of the methodology.

The systematic review method followed the work of Tranfield *et al.,* (2003). A combination of three keywords was used to form a search string. All preliminary searches, therefore, included the key terms "energy consumption behaviours" with "sustainable smart cities" and "SSC technologies" in the publication titles. The initial search acquired 1,224 articles. Screening of relevant articles were executed to ascertain whether the documents were likely to meet pre-determined inclusion and exclusion criteria.

The inclusion criteria included:

Published papers from the current time of writing to 10 years ago (2021-2011)

Papers/articles in the English language

Papers/articles relating to households

Papers/articles with empirical and non-empirical evidence

In addition, the following exclusion criteria were applied:

Papers/articles published in magazines and newspapers

Papers/articles that only provide a review of a conference

Table 1: Search results, thoroughly reviewed papers, and included papers

	Search results	
Initial search		1,224
Preliminary screening	(932)	192
Abstract screening	(83)	109
Full-text screening	(21)	86
Final in-depth review		65

Table 1 summarises the screening and review process of the search results to only 65 articles included for in-depth analysis to be used for synthesis using the MLP lens. After a preliminary screening of the initial search results, abstracts were filtered based on the notion that households generate significant carbon imprint through energy use at home and personal (domestic) Transportation (DECC, 2013). Thereby limiting articles to households' energy consumption behaviour and smart mobility choices as observable components in the urban environment inspected at the household level. The full-text screening examined key terms such as "SSC technology" to determine relevant discussion in the literature. It excluded any that did not explicitly discuss it or detailed energy consumption behaviours discourse, reducing the in-depth review to 65 papers.

Phase 2: Multi-Level Perspective (MLP) Synthesis

The insights into energy consumption behaviours found in all reviewed articles and the gaps discovered are carefully analysed through the MLP lens. Set theory is then used to gauge the relationship presented via Venn diagrams of the three niche processes as the niches analysis method adapted from Smith (2012) Discussed earlier. The observation was made to determine the barriers and challenges SSC technologies encounter at the niche level when attempting to break into the established socio-technical regime by noting SSC technology's influence on households' energy consumption behaviour. Finally, the results are used to postulate SSC technology as a possible urban decarbonisation pathway and address the previously stated research gaps.

FINDINGS

A total of nineteen types of technology were found relating to energy consumption behaviours in the 65 SSC literature reviewed. The highest discussed technology was the smart meter (19), followed by general "smart technology" (13), smart home (6), and smart grid (4). Two articles detailed the Internet of Things (IoT) With electrical vehicles (2) And smart buildings (2). Three papers discussed smart mobility and ICT (3). Other individual papers were about the electric bicycle, smart traffic lights influencing household mobility choices, smart load management, big data analytics, smart net-zero energy homes, Wechat, Web of Things (WoT), smart thermostat, fog computing, and Renewable Energy Sources (RESs). There exist myriad types of SSC technology with a wider range of SSC discussions that determining SSC technology as a decarbonisation pathway becomes challenging. However, taking smart meters as the dominating technology in the analysis, researchers agree on the importance of behaviour in impacting technological initiatives at the household level that would have a more substantial result in changing energy consumption within that sector (Al-Marri *et al.,* 2017).

Synthesis Through MLP Lens

The study observes the dimension of interactions of SSC technologies with energy consumption behaviour in the household sector through MLP levels, namely:

SL Socio-technical landscape observed through climate change (CC) And sustainable future (SF) Factors

SR Sociotechnical regime observed at the household level that SSC technology has to break through

NT niche technology observed as SSC technology/ innovation

It then inspects the SSC technology through Smith (2012)'s niche analysis (LP, EV, SN), as previously mentioned. The finding showed a significant relationship with the dimension of interaction to postulate SSC technologies as a decarbonisation pathway and is described as follows:

Figure 2 reflects the findings where LP intersects with EV but excludes SN as the most interactive relationship (LP ∩ EV = 46). Since most papers reviewed SSC technology as a niche innovation, findings indicate that it is still in the exploratory phase. Therefore, it is not widely diffused to the socio-technical regime level and is yet to be broadly adopted to replace the incumbent system. As a result, it has a low SN, which means more actors need to utilise the technology to make a significant decarbonisation impact.

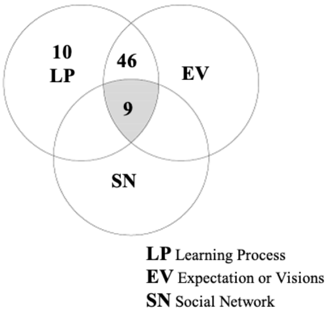


Figure 2: MLP analysis

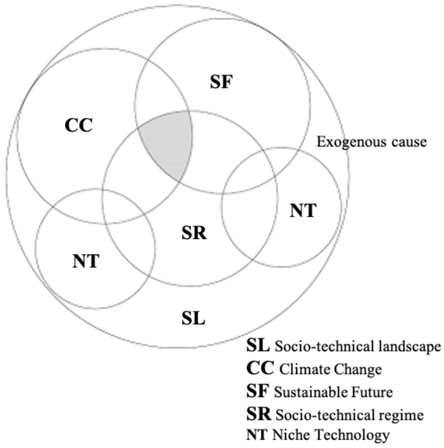
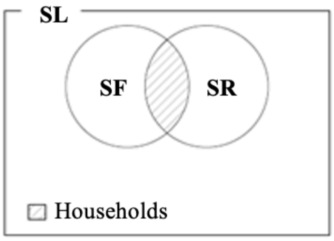


Figure 3: SL components interaction

Therefore, the study perceives SSC technology generally stagnates at the niche level, indicative of SN having a minor intersection. For example, literature discussed smart meters as widely diffused in many households, yet they are still considered a novel innovation compared to more commonly used household technologies. Thus, it may not have a considerable impact on energy consumption behaviours.

Meanwhile, only ten papers discoursed the LP (LP ∩ EV' ∩ SN' = 10) Of technology transition without engaging both EV and SN processes. The learning components for lowering energy consumption include technological potentials (Oki *et al.,* 2019), technical solutions through automation (Mashayekhi and Heravi, 2020), market relation (Al-Marri *et al.,* 2017; Davoudi, 2014), user behaviours (Lopes *et al.,* 2017), privacy issues such as cyber-attacks and health issues (Alamaniotis *et al.,* 2019; Aliero *et al.,* 2021), infrastructure requirements for smart grid system (Masseck *et al.,* 2017; Soares *et al.,* 2016) And policy instruments (Kapoor and Dwivedi, 2020).

Finally, nine papers are considered holistic because they have observed all MLP's socio-criteria of analysis and interact with all three areas to attempt successful technology transition (LP ∩ EV ∩ SN). Using these papers, the study goes on to investigate the relationship of niche smart technology (NT) With other interacting characteristics and themes through the interlocking relationship of socio-landscape (SL) Pressuring socio-technical regime (SR) Explored in Figure 3. This Figure shows that the exogenous cause indicated at the socio-technical landscape level (SL) Are pressurising factors identified as climate change (CC). Changing public environmental awareness and broader social pressure are revealing CC concerns. Secondly, the sustainable future (SF) Factors concerning technological adaptation by addressing urban problems, modern growth, and energy scarcity. As both CC and SF exert pressure on the SR level, it allows the SSC technology breakthroughs from the niche level. The intersection (shaded in grey) Is linked to the relationship between SSC technologies emerging from NT. Despite the climate change factor driving this technology diffusion, it was also found that community-wide initiatives also reduce carbon footprints by 17-27% after two years of intervention in household consumption (Iweka *et al.,* 2019). This indicates that the sociological solution should not be overlooked when technology is used as an urban carbon solution for a sustainable future. The sustainable future (SF) Connections are further explored with explanations through subsequent diagrams.



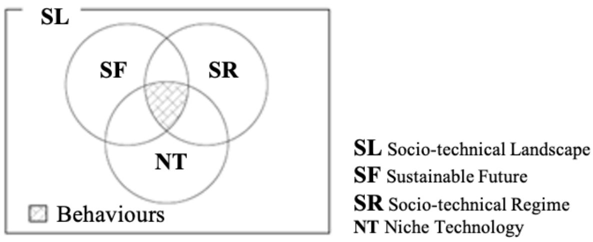
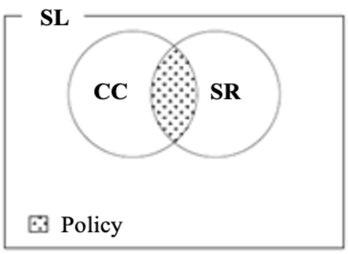


Figure 4: Technology impact in SL   *Figure 5: Smart meter impacts behaviour*

When related elements (SF and CC) Within the SL from Figure 3 were dissected, five papers (Chen *et al.,* 2017; Fjellså *et al.,* 2021; Gupta *et al.,* 2018; Iweka *et al.,* 2019; Westermann *et al.,* 2020) Resulted in the household as the constant intersecting component with SF ∩ SR. As a result, sustainable future (SF) Literature themes are frequently framed around technological adaptation as technocratic solutions aimed at targeting consumption behaviours within the household sector at the SR level, as illustrated in Figure 4. Fjellså *et al.,* (2021) Correlated the irregular behavioural pattern of consumption in most households provided energy providers to rely on automation through technology to bypass the issue. Therefore, when SF ∩ SR ∩ NT interacted, as shown in Figure 5, the technology found to offer a solution to the challenge of behavioural irregularities was the smart meter. The study then analysed the challenges of smart meter application as a niche innovation. Literature indicates that while SSC technology has been adapted as a solution for reducing the carbon footprint at the household level to promote sustainable futures (SF), the influence of household behaviour as an influencing factor cannot be minimised and is the foundation for sustainable futures.



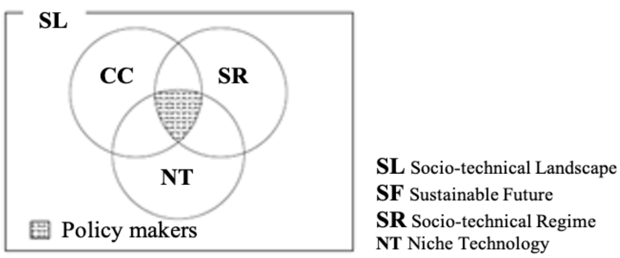


Figure 6: Policy influences in SL   *Figure 7: Disrupting cause in SL*

Nonetheless, concerning climate change (CC) Factors, all four papers (Essletzbichler, 2012; Ingle *et al.,* 2014; Schill *et al.,* 2019; Schröder *et al.,* 2019) From the nine papers examined associated policy, either intervention, the instituting policymakers, or encouraged policy discourse at SL level as the interacting component of CC ∩ SR, as depicted Figure 6. Meaning that policy has the potential to influence sustainable household energy consumption behaviour. When interaction CC ∩ SR ∩ NT in Figure 7 was plotted, the study observed policymakers as the most substantial disrupting factor and barrier to technology transition. Schröder *et al.,* (2019) Posited that niche innovation may disrupt policymakers at the regime level because it involves institutional changes and governance innovation. In contrast, other factors such as socio-politics, human behaviour (Schill *et al.,* 2019), and energy providers (Essletzbichler, 2012) Are also recognised as barriers within the SR components for SSC technology to transition into the regime and impact behaviours toward urban decarbonisation goals.

CONCLUSIONS

City planners are expected to face significant future challenges from overpopulation growth in urban areas. As a result, smart city initiatives are recognised as having the solution that uses connected technology to facilitate efficient city planning and management, with sustainable urban solutions relying heavily on SSC technology to offset carbon concerns. Therefore, by employing the MLP lens, the study concludes that attempting to conceptualise the decarbonisation pathway through SSC technology requires successfully transitioning into the established urban system. Furthermore, ensuring sustainable transition at the household level is crucial since the city population lives in homes, so impacting their energy consumption behaviour infers mitigating carbon footprint at the urban level, and thus may offer sustainability solution in SSC envisioning.

By plotting the relationships of the socio-technical components, the study examined the challenges of SSC technology as a decarbonisation pathway and determined influential sustainable transition factors. Climate change (CC) Factors were found to be the exogenous cause exerting pressure on the established regime that supports the creation of SSC technology as a sustainable future (SF) Solution. However, SSC technology stagnates at the niche level because it is a niche innovation that has not yet achieved widespread adoption. Suggesting that SSC technology may not have the desired influence on household energy consumption behaviour as it has not broken through the regime level.

To counter such a challenge, broader participation at the household level with SSC technology is required, leading to wider technological diffusion at the regime level and a significant urban decarbonisation impact. Therefore, using the MLP framework, the study determined that more robust policy advocacy on the adoption of SSC technology could affect household energy consumption. A bottom-up sociological approach was also established to promote the transformation of the urban fabric to a more sustainable path through SSC technologies adopted in households. Finally, the study's findings contribute to improving the built environment by highlighting the sociological significance of people's participation with SSC technology at the household level resulting in urban decarbonisation and thus supporting the sustainability aspect of the Sustainable Smart Cities to be realised.

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