*energies*

*Article*

# Sustainable Smart City Technologies and Their Impact on Users' Energy Consumption Behaviour

**Hidayati Ramli, Zahirah Mokhtar Azizi * and Niraj Thurairajah**

Faculty of Engineering and Environment, Northumbria University, Newcastle upon Tyne NE1 8ST, UK; hidayati.ramli@northumbria.ac.uk (H.R.); niraj.thurairajah@northumbria.ac.uk (N.T.)
* Correspondence: zahirah.azizi@northumbria.ac.uk; Tel.: +44-(0)191-243-3585

**Abstract:** Sustainable smart cities (SSCs) target decarbonisation by optimising energy consumption through the emerging capabilities of technology. Nevertheless, the energy consumption behaviour of end users has the potential to compromise the effectiveness of technological interventions, reflecting the importance of active social engagement in realising decarbonisation goals. Although extensive research exists on energy consumption behaviour, little is known about how technology engagement affects it, the nature of these technologies, and their role in SSC. The paper aims to identify, categorise, and investigate the smart technologies that impact household energy consumption behaviours and their integration into the larger SSC system. Following a systematic review of 60 articles from the Scopus database (2013–2023), the study found 45 smart technologies cited, with 49% affecting efficiency behaviour and 51% affecting curtailment behaviour. While these technologies inform the city administration level in the SSC framework, the role of end users remains unclear, suggesting a technocratic approach. The study proposes the Sustainable Smart City Network to facilitate a grassroots approach, identifying five key domains: government policies, smart technology adoption, smart technology engagement, smart city infrastructure, and urban sustainability. The study provides an original contribution to knowledge by unveiling the key technologies affecting energy consumption behaviour and outlining the pragmatic requirements for achieving decarbonisation through a grassroots approach.

**Keywords:** smart city; sustainability; smart technology; energy consumption behaviour; energy efficiency; human–technology interaction



**Citation:** Ramli, H.; Azizi, Z.M.; Thurairajah, N. Sustainable Smart City Technologies and Their Impact on Users' Energy Consumption Behaviour. *Energies* **2024**, *17*, 771. https://doi.org/10.3390/en17040771

Academic Editors: Bartłomiej Igliński and Michał Bernard Pietrzak

Received: 31 December 2023
Revised: 30 January 2024
Accepted: 4 February 2024
Published: 6 February 2024



## 1. Introduction

Sustainable smart cities (SSCs) have been lauded as an innovative approach to address decarbonisation through the emerging roles of information and communication technology (ICT) in policy design and urban planning [1]. This has manifested in the establishment of over 5550 smart cities worldwide [2] and the development of smart city planning policies globally [2]. However, empirical support for the sustainability of smart cities remains limited, as they exhibit only marginal improvements in sustainable outcomes compared to non-smart cities [3]. The United Nations Economic Commission for Europe (UNECE) [4] defines a sustainable smart city (SSC) as "an innovative city that uses information and communication technologies (ICTs) and other means to improve quality of life, the efficiency of urban operation and services, and competitiveness while ensuring that it meets the needs of present and future generations concerning economic, social, environmental as well as cultural aspects". This aligns to enable society to advance, survive, and govern the planet more intelligently towards urban sustainability with the help of smart technology [5]. SSCs were conceived as a response to challenge the predominant reliance on technocentric strategies in achieving the desired sustainable future development of smart cities. By prioritising low-carbon solutions, a SSC aims to contribute to an overall reduction in energy consumption, aligning with the sustainable goals of smart cities [6].

The idea primarily revolves around increased information communication technology (ICT) efficiency through what has become known as the 'digital economy'. Smart cities seemingly offer a utopian vision of urban integration, efficiency, and subsequent carbon reductions [7]. While integrating smart technologies has undoubtedly enhanced the operational efficiency of smart cities and facilitated access to crucial energy data, there is no direct correlation between smart cities and environmental sustainability [1]. In many cases, the actual energy savings of buildings were overestimated due to variations in the actual occupants' energy consumption behaviour [8,9].

Thus, reducing the carbon footprint is not simply about developing energy efficiency measures with technological support, but necessitates social behavioural change, specifically, changing our energy consumption behaviour in everyday practices and adopting more sustainable living patterns [10,11]. In theory, combining information and feedback mechanisms through smart technology increases the likelihood of behavioural change [12]. Since smart technology typically involves capturing data through embedded sensor networks and technology use, it is crucial to recognise its potential impact on household energy consumption behaviour. This is because the behaviours and environments in a SSC are shaped by interacting variables that influence each other bidirectionally [13]. Addressing household-level energy consumption is imperative for maximising energy efficiency, given that household carbon emissions accounted for approximately 72% of global and 15% of greenhouse gas emissions in the UK in 2019 [14]. Despite these significant figures, decarbonisation solutions often neglect the involvement of end users responsible for such a substantial carbon footprint [15]. It is crucial to emphasise that energy consumption in cities, like any construction or infrastructure, is fundamentally driven by people [7]. Consequently, there is a pressing need for a deeper understanding of how smart technology can influence household energy consumption behaviour, particularly since SSCs leverage innovative, data-driven technologies to promote urban sustainability [16].

The paper aims to identify, categorise, and investigate smart technologies that impact household energy consumption behaviours and their integration into the larger SSC system. To achieve this, we conducted a systematic review and in-depth analysis of literature from the Scopus database. However, our paper extends beyond a traditional literature review by identifying and categorising smart technologies and critically analysing their impact on household energy consumption within the SSC framework. We further address key research questions to uncover smart technologies discussed in the SSC literature and explore the information provided by them concerning smart technologies that impact household energy consumption behaviour, which then conceptualises the technologies' integration within the broader SSC system. Conducting a thorough analysis, we then mapped the technologies at the household level, uncovering a dominant top–down, technocratic approach to smart energy management. We adopted the ITU-T Series Y framework [17] and Feng's model [5], and subsequently, our work enhances the existing knowledge by extending the framework and incorporating the layered approach from the model mentioned. Despite the broad nature of these frameworks, they do not address the human-to-technology interaction with these smart technologies at the household level nor exemplify how they may impact energy consumption practices. Therefore, our work bridges this gap by exploring household technology interactions within the SSC framework, enabling a comprehensive understanding of the technology layer of households in the system. The study reinforces the importance of incorporating a social dimension in technology interventions [18] due to the uncertainty of achieving energy reduction without active citizen engagement [19].

In response to these findings and to overcome the limitations of the adopted frameworks, we propose an innovative model that integrates smart city principles with citizen-centric strategies from the ground up. This enriches our understanding of how smart technology influences household energy behaviours and establishes a meaningful connection with existing research. It adds a new dimension to the field by advancing our comprehension of the interplay between smart technologies and energy consumption behaviour in the context of SSCs.

The structure of this study is as follows. Section 2 explores the socio-technical perspective of sustainable smart cities (SSCs) and pertinent frameworks. Section 3 outlines the methodology used in the literature research and review. Section 4 presents an analysis of smart technologies based on a review of 60 papers, summarising findings in a table and appended to this paper. This section also includes a graphical representation of smart technologies within a multi-tiered SSC ICT architecture, examining the behavioural aspects of household interactions with technology. Section 5 elaborates on the development of the multi-tiered structure discussed earlier, which maps human–technology interactions at the household level, drawing on the graphical synthesis from the previous section. It also discusses the Sustainable Smart City Network Model, which adopts a citizen-centric approach to smart city systems through enhancing the research findings, analysis, and overall synthesis. Section 6 concludes the study, while Section 7 outlines the limitations and provides recommendations for future research.

## 2. Socio-Technical Perspective of Sustainable Smart Cities

The emerging capabilities of technology have resulted in the incorporation of smart technology to digitally connect and coordinate various urban systems in an overarching information system [17]. According to Feng [5], the rapid development of cutting-edge technologies such as artificial intelligence (AI), Internet of Things (IoT), big data, cloud computing, robots, virtual reality, and ICT, which are all part of smart city technologies, may develop the smart city architecture into a human brain-like function. The concept anticipates that, besides having visual, auditory, tactile, and motor nervous systems, these smart technologies will eventually evolve the city, similarly to how the human brain functions, as indicated in Figure 1. The City Brain, as envisioned by Feng [5], can achieve human–human, human–things, and things–things information interaction through the city neural network (Bis SNS) and achieve a rapid smart response to city services through the cloud reflex arcs, with the support of the city central nervous system (cloud computing), the city sensory nervous system (cloud computing), the city motor nervous system (Industrial Internet), and the city nerve endings (edge computing).

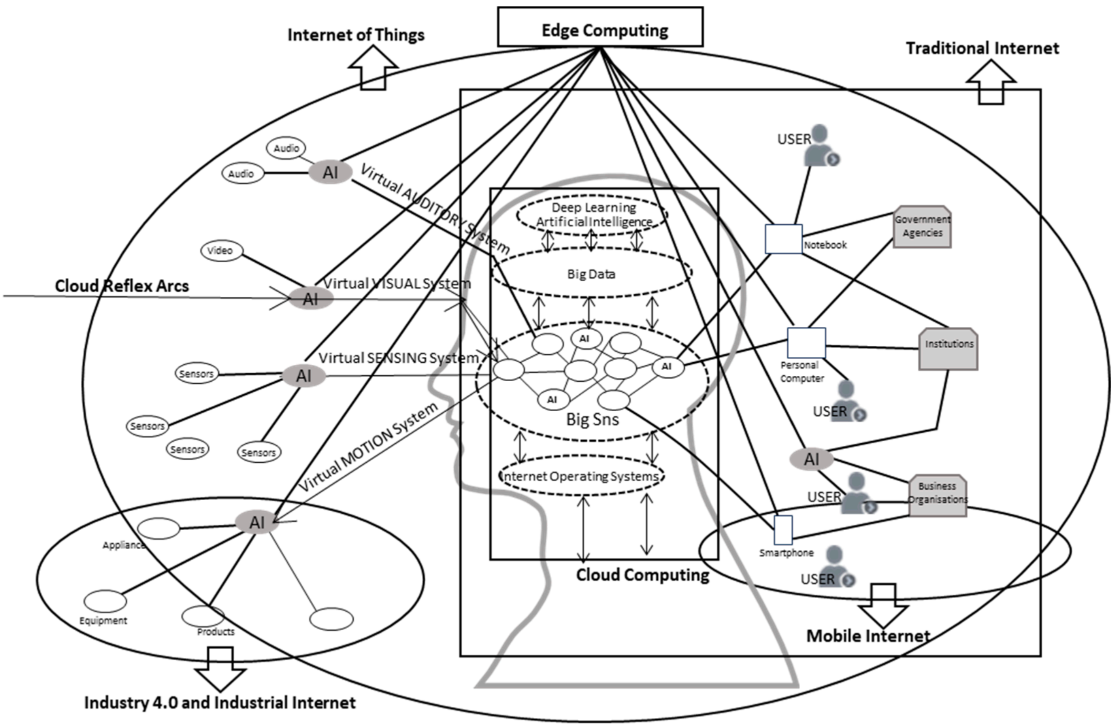


Figure 1. Architecture chart of the construction of the City Brain.

Similarly, the International Telecommunication Union (ITU) has proposed standards for leveraging ICT in smart city platforms to achieve urban sustainability [4]. More specifically, it has also been depicted that ICT contributes to all of the SSC dimensions (people, living, government, mobility, economy, and environment), which means that alternative ICT solutions such as IoT, telecommunication networks, cloud computing, and cybersecurity play a key role in SSC development [17]. As illustrated in Figure 2 below, the framework organises ICT interfaces between six layers of interaction.

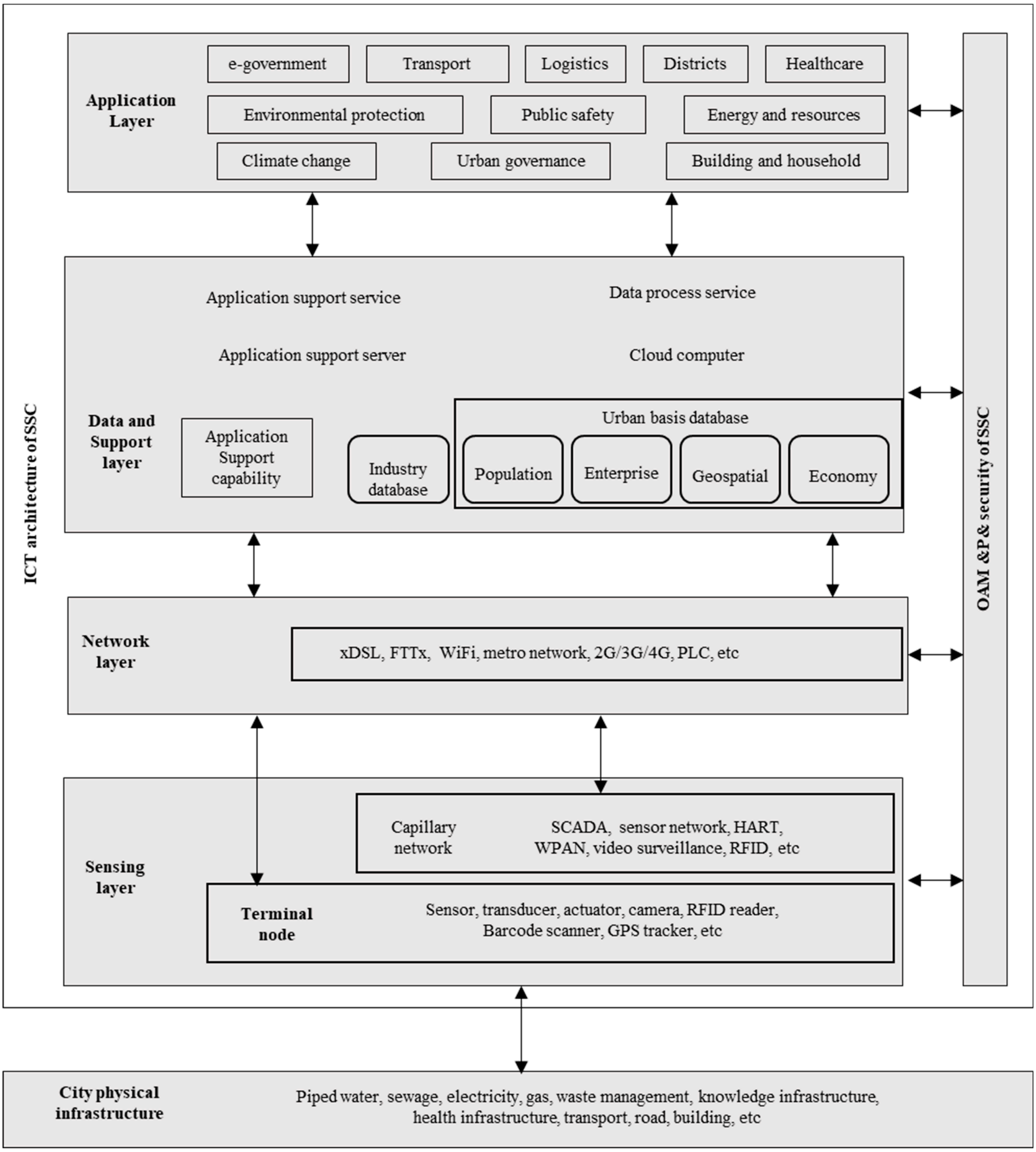


**Figure 2.** A multi-tier SSC ICT architecture from a communications view, emphasising a physical perspective [17].

The first layer is the city infrastructure data that sends data via the second and third sensing layers. The fourth and fifth interfaces are the data and support layer for the SSC application. Finally, the sixth layer connects all communication interface points within the operation, administration, maintenance provisioning, and security functions for the SSC's ICT systems. This framework categorises infrastructure development as 'hard infrastructure-based' and 'soft infrastructure-based' approaches. The former focuses on the efficiency and technological advancement of the city's physical systems such as transportation and energy. At the same time, the latter emphasises the city's social infrastructure and human capital including knowledge, inclusion, participation, and social equity. Both approaches prioritise ICT management.

However, both frameworks overemphasise technological innovation risks, reducing sustainable urbanism to mere physical infrastructure and urban technological systems, where human behaviours are simply data points supporting the automation of a city built on a data economy [20]. Insights from science and technology studies (STS) highlight the importance of considering the broader socio-technical relationships (human–technology interaction). Consequently, smart city discussions should encompass interdependencies and socio-technical perspectives [21,22], suggesting a shift from a top–down approach in smart city design and policy to a co-governance model that aligns with the complex socio-technical nature of smart cities [23]. We expand this discourse by supporting a more sustainable approach that should incorporate socio-techno solutions. SSC is conceptualised as an interdependent smart urban ecosystem supported by a bottom–up strategy accomplished by individual actors' foundational roles in the city's operation.

Therefore, given the socio-technical nature of an SSC, the study attempts to comprehend the sustainable smart city framework from the bottom–up perspective of the household level, which covers the sociological aspect of energy consumption behaviour and how the interaction with smart technologies impacts it.

## 3. Materials and Methods

The study employed a systematic literature review approach to filter the discourse in the SSC literature about smart technology's impact on energy consumption behaviours. The method of scientific investigation followed the work of Transfield [24], who developed a systematic review methodology for evidence-informed management knowledge and composed the systematic review process in two phases: research-review literature and analysing-synthesising literature. The modified systematic review process, which comprises several distinct phases, is illustrated in Figure 3.

Utilising the Scopus database, a combination of four keywords was used to form a search string. The initial search within sustainable smart city research acquired 3836 publications. Following the screening within the result, the keywords "smart city technologies", AND "behaviour", AND "energy consumption" AND "carbon" were used to narrow down the results towards the study's topic. The pre-determined inclusion and exclusion criteria were also followed, limiting the study's 10-year time frame from 2013 to 2023 as the current year of study conducted.

The inclusion criteria included:

- Published papers/articles since 2013–2023;
- Papers/articles in English language;
- Papers/articles that specifically address in their title, abstract and keywords:
- (sustainable AND smart AND cities) AND (smart AND city AND technologies) AND (energy AND consumption) AND (behaviour) AND (carbon);
- Papers/articles relating to households and in the urban context;
- Papers/articles with empirical and non-empirical evidence;
- Conference-proceeding papers.

In addition, the following exclusion criteria were applied:

- Papers/articles published in magazines and newspapers;

- Irrelevant topics on business, management and accounting, mathematics, economics, econometrics, finance, agricultural and biological research, biochemistry, genetics and molecular biology, chemistry, earth, and planetary science.

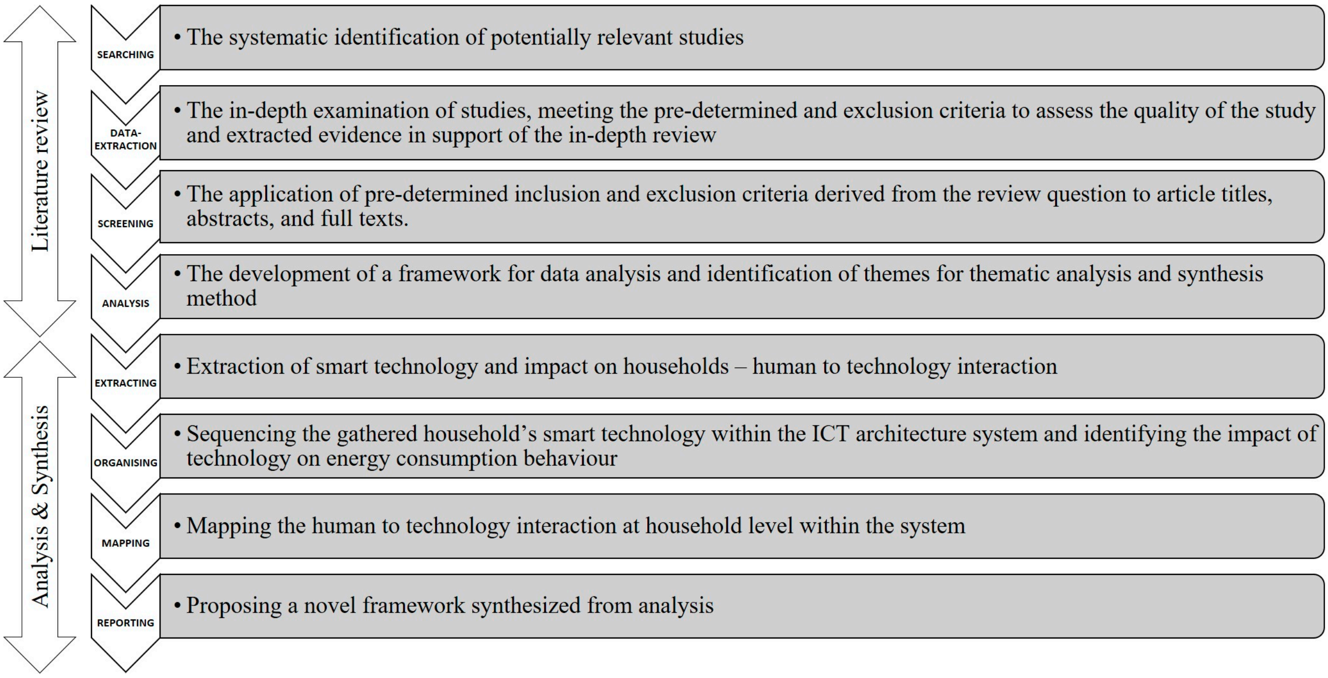


**Figure 3.** The systematic review process and synthesis of findings.

The full-text screening used keywords, specifically "technology", to ascertain the types of technologies the reviewed papers addressed and discarded them when it did not specify the technology within the terms of "smart" technology, was not relevant to decarbonisation, or did not detail energy consumption behaviours, finalising the detailed in-depth review to 60 papers, as shown in Table 1.

**Table 1.** Search results, thoroughly reviewed papers, and included papers.

| | Keywords | Search Results | |
|---|---|---|---|
| Initial search | Sustainable Smart City | | 3843 |
| Preliminary screening | Smart City Technologies | (567) | 3276 |
| | Behaviour | (2479) | 797 |
| | Energy Consumption | (547) | 250 |
| | Carbon | (132) | 118 |
| Abstract screening | Exclusion criteria | (13) | 105 |
| Full-text screening | | (36) | 69 |
| Final in-depth review | | (9) | 60 |

To systematically explore the smart technologies influencing household energy consumption behaviours and their integration into the broader smart sustainable cities (SSCs) system, an in-depth review of the SSC literature was undertaken. In pursuit of this objective, we formulated the following research questions: (1) Which smart technologies are specifically referenced in articles related to sustainable smart cities (SSCs)? (2) What information do these articles provide regarding the potential influence of identified smart technologies on household energy consumption behaviours? (3) How do the identified smart technologies integrate within the broader SSC system?

To address these research questions, we applied a multi-step review process. We began our analysis with an in-depth examination of smart technologies to evaluate their impact on household energy consumption behaviour. We meticulously extracted these technologies from the literature. The data obtained are provided in Appendix A, Table A1.

Next, we organised the technologies along with descriptions of how they are used and interacted with by individuals (i.e., function/usage), according to their respective levels within the smart city ICT system structure, guided by the frameworks of Feng [5] and ITU-T Series Y [17]. This organisation helped us understand the ICT system structure in a sustainable smart city (SSC) architecture and systematically catalogue the technologies mentioned in the literature. Our goal was to identify which smart technologies are encountered, used, and interacted with at the household level and to explore how these interactions influence consumption practices within the SSC framework. The classification of technologies, their layers, and their potential impact on energy consumption are documented in Appendix A, Table A2.

With the information from Table A2, we conducted a synthesis to discern key patterns and insights. This synthesis led to the creation of a graph that visually represents the interactions between smart technologies and their respective layers, emphasising their potential effects on household energy consumption behaviour. We further categorised the technologies based on their impact on energy consumption, distinguishing between those that enhance efficiency and encourage curtailment behaviour. These illustrations are discussed in the subsequent Section 4, delving into all the technologies and synthesised findings to align with the ITU-T Series Y [17] framework and extend it to include the layers determined from the previous analysis. This allowed us to map the human–technology interactions at the household level within the broader context of SSC ICT system interaction and architecture.

Finally, building upon the foundational elements of the established frameworks, we propose the Sustainable Smart City Network Model. This innovative model incorporates five key components highlighting a socio-technical transformation, beginning at the household level through consolidating our research findings, rigorous analytical process, and the comprehensive synthesis of data that shapes it.

## 4. Results

### *4.1. Identifying Smart Technologies and Their Applications in the Smart City System*

To understand the system's smart city organisation and how smart technology impacts behaviours, as discussed in the literature reviewed, it is essential to define and ascertain its application based on the layers of its internal organisation. Consequently, this study adopted the system organisational layers mentioned in the previously examined model [5], integrating them within the structural framework of our analysis.

First, the intra- and inter-system relationships were observed to differentiate which technologies users interacted with (intra) and which were outside interactions (inter). Therefore, the intra-system connection was termed the 'human–technology interaction', in which smart technology products are applications with which people have direct interaction and use (engagement) [25]; therefore, it is an intra-system network. Meanwhile, inter-systems are the relationships of all the smart technology components outside the direct human–technology interaction. For example, the smart grid is a technological component in the smart city platform that impacts end users through households connected to the grid. However, people living in those households are not directly operating the technology. The research then organises 'technology interaction' as layers of system components of ubiquitously embedded intelligence that interact, support, gather, and compute data from people's technology usage to be administered in a system/data management centre (i.e., utility companies). The study uses the work of Feng [5], in which smart technology is conceptualised like a human nervous system and expands the layers mapped in Figure 2 to build the layers of human-to-technology interaction organised at the household level. Therefore, data from technological usage detected via the Sensing Layer is classified as the Sensing Nervous System, while the Sensing Organs are the Terminal Node and Capillary Networks. Likewise, the Application Support Service Data, Process Service, and Application Support Server are grouped in the Data and Support layer because the technologies in this tier operate as supportive components, easing the load of data acquired from the Sensing Layer to be administered at the System Management level. Finally, the study maps out a sustainable smart city ICT system architecture where the Network Layer is recognised as the connecting component of system-level interactions. These layers are then used to group the technologies discussed in the reviewed articles into categories that may impact household energy consumption behaviour. Further details of the smart technologies and their organisational layers within the system are shown in Table A2 in the Appendix A as well as the implications concerning their impact on energy consumption behaviour.

### 4.2. Smart Technologies at the Household Level within the ICT System Structure

The study found 92 types of smart technologies from the 60 articles reviewed. To better understand these smart technologies concerning energy consumption, they were identified within the determined layers of human–technology interaction (HTI), technology interaction (TI), and energy system management (ESM). Of these, the most widely discussed technology was the smart grid, which received 21 mentions and was categorised under the energy system management layer because it is a city energy grid system. Thus, people in households do not directly interact with the system even when the smart grid is central to the SSC concept to better manage the household's energy. There were 16 smart technologies included in this category.

Out of 116 mentioned in the literature, 45 smart technologies were recognised as having an active interaction with the users at the household level and labelled under the HTI category. These technologies were further separated into two sub-categories (i.e., products and applications). Products are devices that people can install such as high-energy heat pumps, LED low-power lighting, solar energy panels, solar water heaters, and thermal solar panels. Another is technologies, which are built infrastructure such as smart buildings (13), smart homes (9), and zero carbon buildings (3). Finally, the technology interaction (TI) layer captures data from the technologies that people interact with via the Internet of Things (17) through smart sensors (12), stored in cloud technology (12), and mined via big data (10). Meanwhile, the network layer and ICT mentioned were outside these categories as they are the whole network. These technologies and layers are displayed in Figure 4.

Exploring the layers of SSC architecture revealed a multiple interconnecting system that collects (TI) and manages (ESM) behavioural data from smart technologies that individuals engage with (HTI). Therefore, when discussing smart technologies as having the potential to maximise energy efficiency, we must consider the dimension of interaction between these technologies and human users, which eventually supports grid-linked technologies and smart urban networks. Most articles reviewed the smart grid as having the potential to reduce energy consumption via efficiency and curtailment strategies, to shift use to off-peak times of day, and to enable distributed storage and generation options that all involve a significant amount of human involvement and engagement [21]. Although end users play a central role in these systems, they are often overlooked in smart technology and urban design, and their motivations for participating in such systems are not always fully understood [26]. Consequently, understanding the individual's interaction with these technologies would further enhance the technological impact on energy consumption behaviours and energy conservation.

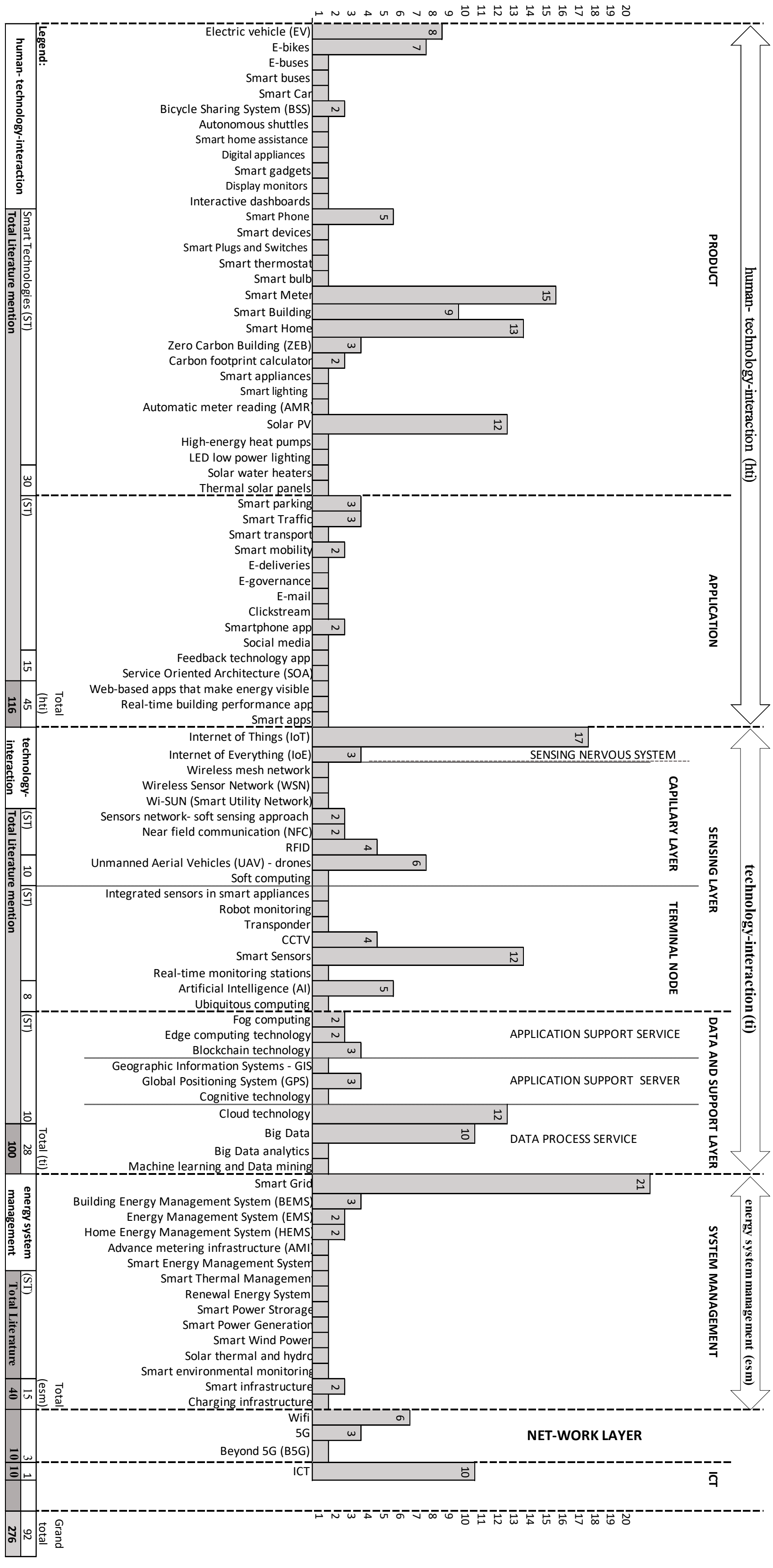

**Figure 4.** Technologies organised in the multi-tiered SSC ICT architecture of system interaction.

*4.3. Human–Technology Interaction at the Household Level and Its Behavioural Impact*

Extracting from Figure 4 and narrowing on the exploration of human–technology interaction as displayed in Figure 5 below, the study observed behaviours related to household energy conservation and were impacted by smart technology engagement in two categories: efficiency and curtailment behaviours.

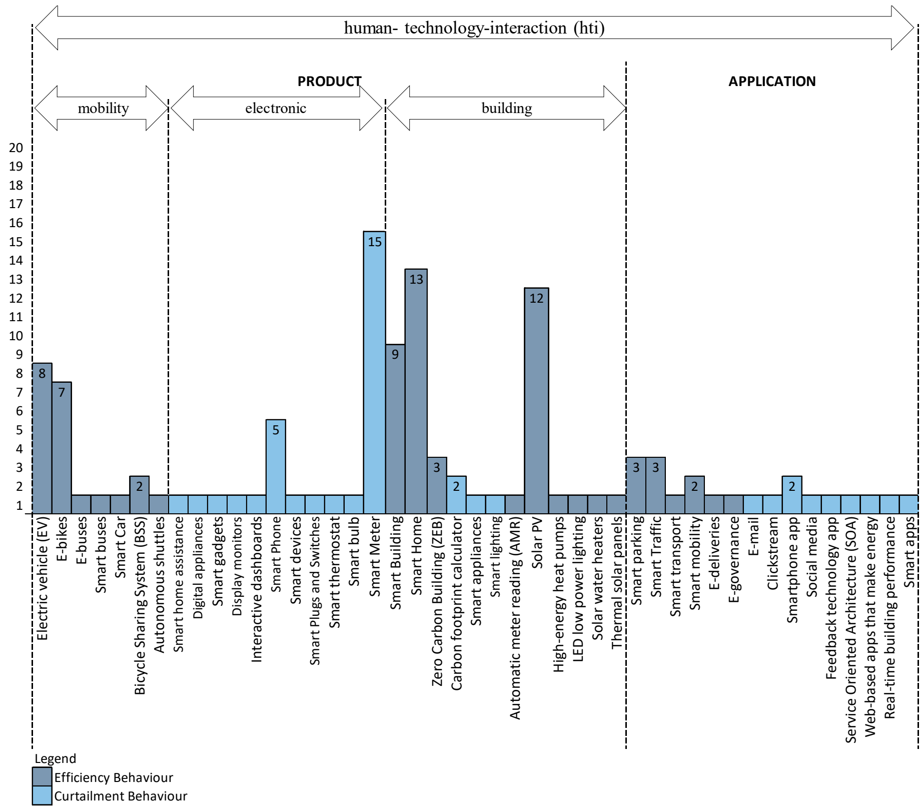


**Figure 5.** Smart technologies that affect efficient and curtailment behaviours.

Curtailment entails operating equipment less frequently or intensively [27,28]. However, producing savings requires repetition, which involves voluntary participation in curtailing usage. On the other hand, efficiency behaviours typically involve capital investments and do not require the same level of repetition or behavioural maintenance [26]. Likewise, high-energy heat pumps and smart homes are considered one-time behaviours and are recognised as a more efficient behavioural type that requires a one-shot investment. Meanwhile, smartphones, digital appliances, and smart meters require repetitive efforts and interaction with these smart technology products and, therefore, are categorised under curtailment behavioural types since the interactions are more operational. However, e-bikes, electric vehicles, smart cars, and smart buses have efficient and curtailment behavioural characteristics. They involve a financial investment and a change in lifestyle such as charging vehicles and building smarter infrastructures for their use. Although these technologies require an operation, they are more efficient as they autonomously curtail carbon imprint through repetitive use.

Having this distinction in an energy conservation strategy is crucial to understanding energy consumption behaviour concerning the impact of technology since energy consumption is not a behaviour but a consequence of behaviours [29]. Therefore, although the energy-saving potential of efficiency measures (22 types of technologies reviewed) is considered greater than that of curtailment behaviours (23 types of technology products), energy-efficient technologies do not necessarily result in a reduction in the overall energy consumption when they produce the rebound effect, whereby people's carbon footprint increases due to thinking that such installed technologies are already saving their energy use [30]. Here, the importance of the interplay between macro-level (e.g., technological innovations) and micro-level factors (e.g., knowledge of efficient use of technological innovations) becomes apparent [12]. That is to say, technological innovation necessitates sociological support such as identifying underlying determinants of energy use and better policies to support smart technologies that result in efficient energy use at home as well as improving the users' energy conservation knowledge to enhance curtailment behaviours.

Installing technologies such as prepayment gas meters introduces repetitive feedback, contributing to a reduction in gas usage [31]. This exemplifies a technological intervention that facilitates more sustainable consumption. However, the success is attributed not solely to the technology itself but to the knowledge it provides, prompting users to alter their energy consumption. This confirms that technologies falling into the curtailment category such as voluntary demand response, time-of-use pricing programs, energy feedback, and disaggregated feedback necessitate continuous consumer participation to achieve energy reductions. Voluntary curtailment relies on consumers to undertake a series of decisions and actions including repetitive behaviours of (1) attending to the alert, (2) mentally cataloguing energy use in the home, (3) deciding what action(s) to take to reduce energy use, (4) executing such actions, and (5) maintaining this lower level of use over some period [26]. These repetitive efforts may spill over into other pro-environmental behaviours as people use their past sustainable activities as a barometer of their own environmental identities, which showcase a more sustainable behavioural impact.

Consequently, the highest technology in the HTI category is the smart meter (15 mentions) since an SSC conceptualises smart meters to support the smart grid system. Smart meters are required for a smart grid to operate effectively because they record hourly energy and gas consumption and communicate with utility companies for better monitoring and billing. It displays the daily energy usage, making it easier to make strategic decisions about electricity usage and costs. As a result, because people interact with the smart meter through its feedback technology, it has the potential to significantly influence the users' energy consumption behaviours. The feedback feature is frequently promoted as having the potential to increase energy efficiency by causing people to reduce their energy consumption during peak demand hours [32]. However, studies show that the effects of behavioural curtailment strategies fade over time, raising concerns about their long-term effectiveness [26]. People often have inaccurate perceptions about the impacts they can make with various energy conservation behaviours [29]. As a result, maximising the impact of efforts necessitates considering the longevity of savings and the accuracy in curtailment forecasting provided by smart technologies such as smart meters. Meanwhile, energy efficiency technologies such as electric vehicles and solar panels require one-time or infrequent behaviours. Although the technologies require high upfront costs, they offer long-term energy conservation potential and require minimal ongoing consumer effort. Nonetheless, widespread adoption in household use has proven challenging due to higher upfront costs, privacy/autonomy concerns, and technical barriers commonly associated with the efficiency of smart technology [33].

To gain a deeper understanding of how household energy consumption data functions within the sustainable smart city (SSC) system, we examined the data within the existing SSC system structure, which resembles a city's neural network. By organising the system's components as shown in Table A2 (see Appendix A), this study demonstrates the 'flow' of data from extraction to optimising energy consumption through smart management, which paves the way towards meaningful automation. Energy usage automation is a compelling technological proposition because human behaviour is challenging to predict, but it does not mean that it cannot be influenced. Therefore, social factors must be considered through social cognitive theories with technology hinged on social-technical learning models that can understand the relationship between technology and its energy consumption. In other words, smart technology alone is insufficient for changing habitual energy consumption habits because individuals must be informed about the need for and methods to reduce energy consumption, be motivated to reduce energy use, and be committed to behaviour change [34].

## 5. Discussion

### *5.1. Mapping Human–Technology Interaction at the Household Level within the Multi-Tiered ICT System*

Following the findings on the technology categories most relevant to influencing people's energy consumption behaviour, the study illustrates a multi-tiered SSC ICT architecture of system interaction to highlight the interchange of information from the users' engagement with smart technology use, as presented in Figure 6. The layers are mapped to explain the interaction of each technological layer in a SSC framework and how technology is applied to analyse and understand how a household's energy consumption data 'flows' within the smart city platform and network.

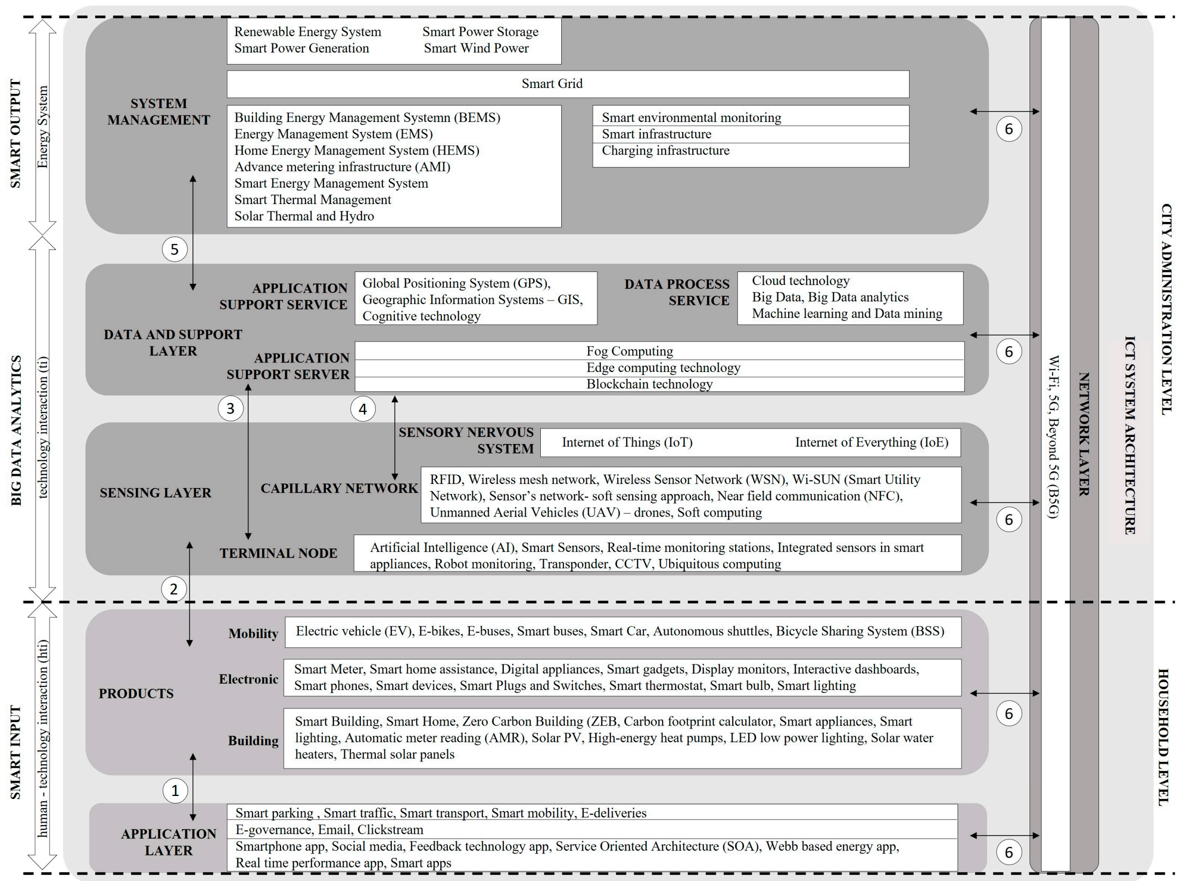


**Figure 6.** A multi-tiered SSC ICT architecture of system interaction, mapping human–technology interaction at the household level (author's illustration based on the ITU-T Y-series recommendations [17].

To begin, the interaction is the communication interface between the layers, which are indicated with numbers in circles and are the main point of standard specifications referred to as communication interface points. The layers are all connected over the internet network, which enables the ICT system architecture to extract data from users at the household level from their smart technology products and smart appliances, in which each interface simultaneously and bidirectionally exchanges information as inputs from household level behavioural data mined by big data analytics technologies and interprets as the outputs at the system management level.

Following the ITU-T Series Y [17] framework and applying Feng's [6] explanation of a brain-like network of a smart city, this study reinterpreted the functions at each of these reference points to indicate the energy consumption data 'flow' from households within the system structure as follows:

- Communication interface point 1: These exist in human-to-technology use and are connected via sensors in smart products or over the network, allowing information to be transferred to the Application Layer. Smart technology is integrated with IoT features that connect the users' smart devices to the application installed in their smartphones so that they can send data to the second interface layers.
- Communication interface point 2: These occur between the human-to-technology use and the Sensing Layer. It allows terminals to sense the physical world by exchanging information and control signals between Terminal Nodes in the Sensing Layer and embedded sensors. Through the connection of IoT-connected smart technologies, both layers collect the users' data from the integrated technologies in the city network.
- Communication interface point 3: These exist between the Terminal Nodes in the Sensing Layer linked by the network. Terminal nodes can reach the Network Layer directly or through net gates, bypassing the Capillary Network to deliver data.
- Communication interface point 4: This occurs between the Capillary Network in the Sensing Layer and the Network Layer. Capillary networks collect sensing data and connect to the support layer to deliver data.
- Communication interface point 5: This point exists between the Data and Support Layer and the System Management Layer. It enables the collection of energy consumption data to data centres. It supports functionalities that provide information to corresponding applications and services as well as integrated applications exchanging data via data centres and application support functionalities to manage data collected from humans to technology usage.
- Communication interfaces point 6: This is between the network connection and all levels. It permits connectivity between data centres and lower tiers to collect various information via communication networks.

### *5.2. Multi-Tiered ICT System Interaction Architecture for Smart Technologies at the Household Level in Sustainable Smart Cities (SSCs)*

In Figure 6, smart technologies at the city level are administered in a more linear top–down structure. This structure modulates smart technology use at the household level as a "smart input" from the bottom up and extracts the users' data collection as a "smart output". Many of the smart technological interfaces connected via the Network Layer are outside human interaction as they are embedded within the city or building infrastructures that become the 'façade' of the SSC concept. Meanwhile, the household is where people consciously adopt, use, and interact with these technologies daily, making them active users who consume energy. Because these technologies are based on interacting variables in which behaviours and environments influence each other bidirectionally, determining the human–technology interaction within the context of the ICT system architecture is essential. As a result of mapping the technological interface communication, we discovered that an SSC intervenes via a techno-centric solution based on top–down technology diffusion that leverages people's behavioural data to optimise efficient urban administration. The data deluge via sensing layers that connect to all feasible smart products allows for more meaningful automation measures at the city system management level that can estimate "smart output" from user behavioural patterns due to data analytics that can better predict energy consumption decisions. However, behaviour anomalies are one of the challenges of the constant surveillance of people's behaviour that has little to do with consumption value [35]. Subsequently, predicting energy consumption decisions is challenging, particularly for residential consumers. Energy practises are unpredictable because they are influenced by variables such as specific user lifestyles and other determining factors [36]. Understanding behaviours is, therefore, imperative for fostering citizen engagement in co-creating smart solutions within smart city models. A significant gap exists in adopting a holistic citizen-centric approach with governmental frameworks that aim to empower citizens to reduce energy consumption [15]. Consumption patterns are intricately linked to how various activities and entities are organised rather than driven solely by individual preferences and systemic paradigms. Practices can be seen as a collective distributed demand (behaviour), asserting that participation in practice plays a pivotal role in shaping behaviours [37]. For example, the potential limitations of embedded sensor networks may fail to interpret and control the complex interplay of behavioural variables systematically. This emphasises the need for policies and incentives that are better aligned with the complexity of human behaviour, advocating the need for a more nuanced and human-centric approach in designing and implementing smart city frameworks.

### *5.3. Scaling the Complexity of the Muti-Tiered SSC ICT Architecture of System Interaction to Household Framework*

As discussed, the study's mapping of household technology interactions within the smart city system architecture revealed a top–down diffusion of smart technologies, where these technologies are employed to enhance urban administration efficiency and optimise economic benefits [38]. However, prioritising the household level to advocate for a citizen-centric approach rather than a purely technocratic perspective demands substantial social engagement to catalyse a socio-technical shift, steering urban development towards sustainability. Therefore, after synthesising the review and findings, this study proposes a more comprehensive sustainable smart city framework, whereby an onion diagram of the ICT system architecture is layered by reorganising Feng's [5] model of the smart city as the Internet Brain. However, we posit that because people at the household level are the ones who use these smart technologies, sustainability is essentially a bottom–up approach that requires co-governance support to effectively engage citizens in the bidirectional relationship between behaviour and the environment. Technology and sociological variables such as energy consumption behaviours must be integrated because habits are commonly formed because of decreased conscious awareness concerning environmental implications [39]. Therefore, rather than automating energy-related behavioural practises observed through data extraction in smart city architecture, technology interactions should increase moral consideration and awareness through active social engagement to break unsustainable habits and provide incentives that benefit the collective shift towards more energy-saving practises. This shift would result in one of the possible decarbonisation paths that cities can explore to make the socio-technical transition to sustainability.

From a policy perspective, research has not focused on understanding how policy might steer innovation in a specific direction [40] such as supporting the transition of household energy consumption to more sustainable practices. Furthermore, sustainable transition strategies are often reduced to the simple problem of disseminating new and better technologies. At the same time, the reorientation of user practises, power relationships, regulatory structures, mindsets, and public discourses has gone unaddressed [40]. Similarly, the multi-tiered SSC ICT architecture of system interaction illustrates the technocratic approach of optimising smart technologies to manage urban sustainability and the users' practices (i.e., energy behaviours). However, innovation is a social phenomenon, determined not only through technological progress but also by the views and needs of social actors [41]. Therefore, technology is influenced by policy as one part of society, together with other social actors hinged on the sociological aspect to steer the socio-technical transformation of a city towards sustainability [15]. Using this assumption and building on the human–technology interaction illustrated in Figure 6, this study restructures the system analysis of the multi-tiered SSC ICT architecture and reinterprets it further to create a more comprehensive SSC model that orientates data towards user engagement as prosumers rather than consumers. A bottom–up strategy is proposed, with five supportive key components providing orientation and guidance to coordinate the complex process of societal transformation and eventual shift towards urban decarbonisation and sustainability, as illustrated in Figure 7.

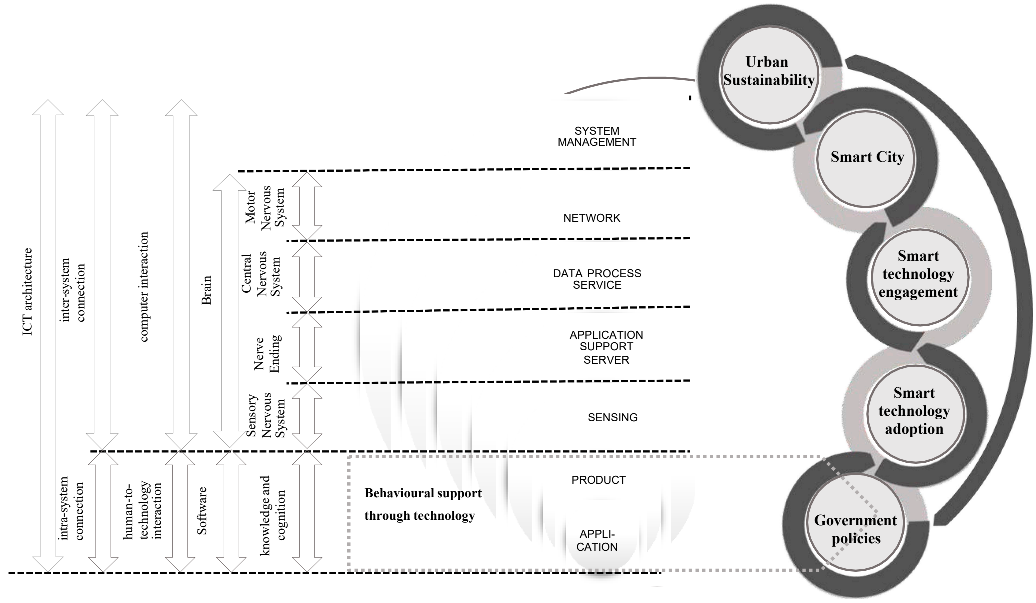


**Figure 7.** Sustainable Smart City Network Model of citizen-centric approach in smart city system.

As shown above, the framework is organised into three interdependent components. The inter- and intra-system components that regulate the ICT architectural layers interact with the exogenous layers of the five key components as the sociological support to drive behavioural change at the household level towards urban decarbonisation and sustainability goals. These five points are interconnected and leverage smart technological innovation as tools to achieve urban sustainability within the SSC network that may rely on technological data from active actor participation and engagement. The social engagement may learn from the innovation towards sustainable practices rather than the smart technologies regulating and mining behavioural data. Therefore, impacting household energy consumption can be accomplished by implementing a more comprehensive framework that comprises more robust support from the sociological components. These components use smart technologies to mitigate urban carbon issues and are conceptualised through: (1) Government policies and incentives, which are crucial for steering innovation and ensuring proactive engagement in socio-technical transitions. Rather than merely optimising techno-economic decisions based on pervasive behavioural data mining [38], policies should facilitate carbon mitigation at the city level by impacting household energy consumption. Incentives must encourage households to adopt, utilise, and engage with smart technologies [42] such as smart meters, solar panels, and smart lighting to promote energy conservation at the domestic level. (2) Smart technology adoption (efficiency behaviour) plays a pivotal role in promoting energy-efficient behaviours within households [43], which is a critical step towards achieving energy conservation. By adopting advanced systems and devices such as smart thermostats, energy-efficient appliances, and home energy management systems [44], households can gain greater control over their energy consumption. These technologies enable real-time monitoring through smart apps and automated energy use adjustments, enhancing the efficiency of household operations and encouraging residents to adopt more conscientious energy usage patterns. (3) Smart technology engagement (curtailment behaviour): Analysing data from smart technologies can reveal consumption patterns and identify opportunities to reduce energy use. This feedback mechanism, facilitated by a smart meter, can inform personalised energy-saving strategies and cultivate a culture of curtailment behaviour [45]. Households become proactive in minimising unnecessary energy consumption, contributing to a sustainable shift in energy practices and collectively reducing the urban carbon footprint. (4) Smart city infrastructure: The adoption and engagement with smart technologies can lead to advancements in smart urban infrastructure, supporting smart mobility [46] and smart grid energy systems [42,47]. This encourages a move away from conventional fuel energy dependency and supports the development of a more sustainable urban infrastructure [43]. (5) Urban sustainability: Ultimately, the widespread adoption of smart technologies and the resulting behavioural changes can drive technological innovation in smart infrastructure towards urban sustainability. Therefore, to effectively mitigate urban carbon challenges, all key components of the proposed Sustainable Smart City Network Model must work in synergy within the data-enriched smart city platform. The model is responsive to and driven by citizen-centric behavioural changes at the household level by leveraging smart technologies to impact energy consumption behaviours, inevitably driving the city towards greater urban decarbonisation on a larger scale towards sustainability.

## 6. Conclusions

The study sought to identify the smart technologies that potentially affect people's energy consumption behaviours. Based on a review of 60 papers, the findings showed 45 technologies with direct human–technology interaction that promoted efficiency and curtailment behaviour. Of these, the majority of technologies cited target curtailment behaviour, while a smaller proportion affected efficiency behaviour. While using technology to promote efficiency is ideal, as it does not require a consistent change in the user's consumption behaviour, it usually involves high capital investments in technologies such as heat pumps, solar energy panels, smart cars, and smart homes. However, enhancing efficiency alone is insufficient to ensure a lasting impact on long-term sustainability, as people's behavioural patterns can also affect energy consumption [48]. Technology such as smartphones, digital appliances, and smart metres demand active user engagement and may influence curtailment behaviour by sharing information and providing feedback on energy use [49]. Other technologies such as e-bikes, electric vehicles, and smart cars may affect both efficiency and curtailment behaviour as they involve financial investments and long-term lifestyle shifts. However, technology-promoting curtailment behaviour is usually preferred by consumers since these have less financial investment as opposed to technology-promoting efficiency behaviour [14]. These technologies have all been examined at the individual household level, but their impact on the wider smart city system is unclear. Thus, the study investigated how human–technology interaction contributes to the smart city system.

Adapted from the ITU-T Y-series [17] framework, the study developed an original multi-tiered SSC ICT architecture of system interaction, mapping human-to-technology interaction in households within the smart city platform level. The results showed a dominant technocentric approach relying on ICT intervention and behaviour automation measures. This coincides with the SSC's sustainability being realised through urban datafication [50], which entails individual or community-level "data acquisition" on behaviours. Data collected through technology-based management systems help inform city administration decision-makers in updating policies, guidelines, and urban design towards city sustainability plans. This information, however, is restricted to the amount and quality of data obtained and data interpretation [51]. It also raises concerns about transparency and ethical data management [52].

Furthermore, technological interventions alone are often insufficient to achieve sustainable outcomes as they also depend on reducing the energy consumption of citizens. Therefore, it is necessary to change the users' energy consumption behaviours, which can be influenced by the insights provided by smart technology, leading to energy savings [11]. This reinforces the need for a holistic citizen-centric approach in smart city frameworks [15]. Thereby, smart technology use and a shift in energy consumption behaviours are needed to achieve effective, sustainable outcomes [53]. The notion is consistent with the assumption that informing people about their daily carbon impact through technology will increase environmental awareness [37]. In contrast, however, Morton et al. [54] discovered that most users were not interested in feedback on their behavioural carbon impact unless it concerned money savings. Thus, it is uncertain if human–technology interaction would improve environmental awareness or promote sustainable habits. Therefore, a more rounded strategy that uses technology intervention to inform and influence the energy consumption behaviour of users is needed to ensure sustainable effects. The study introduced a novel Sustainable Smart City Network Model comprising five key components: Government Policies, Smart Technology Adoption (Efficiency Behaviour), Smart Engagement (Curtailment Behaviour), Smart City Infrastructure, and Urban Sustainability. This model emphasises a socio-technical shift starting at the household level. The model proposes that to achieve a sustainable smart city, it needs robust support and commensurate synergies in all five components, which may leverage technological data to direct each household's energy consumption behaviour towards sustainability.

Finally, the human–technology mapping and novel model significantly contribute to policymakers and researchers establishing a deeper understanding of the smart technologies used in a SSC and how they relate to households within the wider SSC architecture. The paper fills a gap in the literature by taking a socio-technical perspective on SSCs [21,22] by considering smart cities as complex socio-technical systems [23], which may foster a more integrated and citizen-centric approach to smart city development.

## 7. Limitations and Recommendations for Future Research

This study has provided valuable insights into the role of smart technologies in influencing household energy consumption within the framework of sustainable smart cities (SSCs). The research interprets data collected from human–technology interaction (technology engagement) as part of the SSC system's architecture and platform. However, several limitations warrant mention.

Firstly, the findings are confined to the synthesis of smart technologies from the 60 papers reviewed and are subject to the limitations of the ITU-T framework [17] and the Internet Brain model [5] adapted for this study. While these frameworks provided a structured approach to exploring the study's objectives, they may have also limited the analysis to their specific perspectives and assumptions. Additionally, the mapping of household engagement with smart technology within the multi-tiered SSC ICT architecture has led to an interpretation that suggests a predominantly technocratic level of technology diffusion within the stratification of technological interactions in a smart city system platform.

In light of these observations, we recommend further investigation to enhance our proposed Sustainable Smart City Network Model. Future research should explore behavioural models and the variables that impact technology engagement at the household level. Such research could provide deeper insights into how smart technology can influence energy consumption patterns towards conservation practices, an area not extensively covered in this review. The direction of future research should delve into the adoption of smart technology within households, examining socio-economic and psychological factors that influence adoption and subsequently impact household energy consumption and habits. It is crucial to ensure that technology diffusion moves beyond a technocratic approach, which alone is insufficient for changing energy consumption practices. Supporting this recommendation, future studies should conduct comparative analyses of different sustainable smart city initiatives. These studies will help us understand the nuances of policy impact across various contexts and the interplay between technology, policy, and citizen behaviour. A more nuanced perspective on fostering a citizen-centric approach is needed, one that prioritises the needs and behaviours of citizens in smart city initiatives.

As such, policies, as exemplified in our model, are pivotal in this context for further exploration, as they are essential for driving innovation and designing strategies that encourage the widespread diffusion and adoption of smart technologies focused on citizen-engagement strategies. Effective policies can foster proactive engagement in efficiency and curtailment measures that result in sustainable household energy practices. Furthermore, policies aimed at influencing individual energy consumption behaviour through smart technology can facilitate a shift from a technocratic to a citizen-centric approach at the household level. By prioritising the needs and behaviours of citizens, these policies can place them at the forefront of smart city initiatives, furthering the socio-technical transition towards sustainability.

**Author Contributions:** Conceptualization, H.R.; Methodology, H.R.; Validation, Z.M.A. and N.T.; Formal analysis, H.R.; Investigation, H.R., Z.M.A. and N.T.; Resources, H.R.; Data curation, Z.M.A. and N.T.; Writing—original draft preparation, H.R. and Z.M.A.; Writing—review and editing, H.R., Z.M.A. and N.T.; Visualization, H.R.; Supervision, Z.M.A. and N.T.; Project administration, Z.M.A. and N.T.; Funding acquisition, H.R., Z.M.A. and N.T. All authors have read and agreed to the published version of the manuscript.

**Funding:** This research was funded by a Northumbria University RDF studentship RDF20/EE/ABE/AZIZI.

**Data Availability Statement:** Data is contained within the article.

**Conflicts of Interest:** The authors declare no conflicts of interest. The funders had no role in the design of the study, in the collection, analyses, or interpretation of data, in the writing of the manuscript, or in the decision to publish the results.

## Appendix A

**Table A1.** Technologies extracted from 60 papers reviewed.

| No. | Author | Technology Extracted |
|---|---|---|
| 4 | [55] | Smart Grid |
| | [56] | Smart Home, Smart Thermostat, IOT |
| | [57] | UAV |
| | [58] | Cloud computing, NFC, RFID, Sensors |
| 3 | [59] | Smart grid, Smart Meter, IOT |
| | [60] | ICT, AI, Smart home, IoT |
| | [61] | ICT |
| 7 | [47] | Cloud technology, Edge computing technology, Fog computing, Global Positioning Systems (GPS), ICT, Internet of Things (IoT), RFID, Sensors, Smart Grid, Smart Sensors, Surveillance cameras, Unmanned Aerial Vehicles (UAV)—drones, Big Data, Smart Building, Smart Home, E-bikes |
| | [62] | IBS, Big Data |
| | [63] | E-bikes, Smart Traffic, Solar PV, E-deliveries, |
| | [36] | 5G, Electric vehicle (EV), Internet of Things (IoT), Unmanned Aerial Vehicles (UAV)—drones, |
| | [64] | Smart Transport |
| | [21] | E-bikes, Email |
| | [41] | Carbon footprint calculator |
| 9 | [16] | Electric vehicles (EV), Energy Management Systems (EMS), Fog computing, Global Positioning Systems (GPS), RFID, Sensor, Smart Buildings, Smart Grids, Smart Homes, Smart Meter, Ubiquitous computing, Advance metering infrastructure (AMI), Automatic meter reading (AMR), Near field communication (NFC), Renewal Energy System, Smart environmental monitoring, Smart lighting, Smart tickets, Smartphone app, Solar Energy Panels, Big Data, Transponder, Wireless mesh network, Wi-SUN (Smart Utility Network), Retrofit homes, Smart Traffic, Smart transport, Clickstream, smart lighting, Smart Plugs and Switches, Smart bulb |
| | [46] | E-bikes, Smart Mobility, Smart infrastructure, Retrofit homes |
| | [42] | Artificial Intelligence (AI), Big Data, Cloud technology, ICT, Smart Grid, Smart Sensors, Surveillance cameras, Autonomous shuttles, Digital appliances, Digital cameras, Internet of Things (IoT) |
| | [65] | Blockchain technology, Cloud technology, E-bikes, Electric vehicles (EV), Internet of Things (IoT), Smart Building, Smart Grid, Smart Homes, Smart Parking, Smartphones, Smart Sensors, Solar PV, Autonomous cars, Smart Car, Smart gadgets, |
| | [66] | Internet of Things (IoT), Sensor network—soft sensing approach |
| | [67] | 5G, Bicycle Sharing Systems (BSS), Blockchain technology, Electric vehicles (EV), Internet of Everything (IoE), Smart Grid, Smartphone, Building Energy Management Systems (BEMS), Smart Grid, Smart Sensors, Unmanned Aerial Vehicles (UAV)—drones, Smart parking |
| | [68] | Mobile app |
| | [15] | Smart Building, Display monitors, Web-based apps that make energy visible to users |
| | [44] | Big Data, Cloud technology, Global Positioning System (GPS), Intelligent Transportation Systems—ITS, Internet of Things (IoT), Smart Meter, IBS |

**Table A1.** *Cont.*

| No. | Author | Technology Extracted |
|---|---|---|
| 11 | [69] | Internet of Things (IoT) |
| | [44] | Smart Grid, Solar PV |
| | [70] | Smart Building, Smart Home, Zero Carbon Building (ZEB), Smart parking |
| | [71] | Sensor network—soft sensing approach, Smart Grid, Smart Home, Smart Meter, Solar PV, Smart Thermal Management, Solar thermal and hydro |
| | [72] | Smart Meter, Automatic meter reading (AMR) |
| | [73] | Bicycle Sharing System (BSS) |
| | [74] | Building Energy Management Systems (BEMS), Intelligent Transportation Systems—ITS, Smart Grid, Smart Meter, Solar PV, Zero Carbon Building (ZEB), |
| | [38] | System Platform |
| | [75] | Big Data, Cloud technology, Internet of Everything (IoE), RFID, Smart Building, Smart Grid, Smart Meter, Cognitive technology |
| | [43] | Smart Grid, Solar PV |
| | [54] | Smart Grid, Display monitors, Interactive dashboards, Social media, Web-based apps that make energy visible to users |
| 3 | [50] | Artificial Intelligence (AI), Big Data, Cloud technology, Electric vehicles (EV), Internet of Things (IoT), Smart Buildings, Smart Homes, Smart Meters, Smart Traffic, CCTV, Smart Energy Management System, Robot monitoring, Smart buses |
| | [76] | Big Data, Cloud technology, Internet of Things (IoT), Smart Grid, Zero Carbon Building (ZEB) |
| | [77] | Smart Meter, Geographic Information Systems—GIS |
| 5 | [78] | Internet of Things (IoT), Smart Building, Smart Grid, Smart Home, Smart Sensors, Wi-Fi, Integrated sensors in smart appliances, Smart lighting |
| | [79] | Soft computing |
| | [67] | ICT |
| | [80] | ICT |
| | [81] | Smart Meter |
| 7 | [35] | Cloud technology, Internet of Things (IoT), Smart Grid, Smart Home, Smartphone, Smart Sensors, Solar PV, Ubiquitous computing, Wi-Fi, E-governance, Service Oriented Architecture (SOA) |
| | [82] | Artificial Intelligence (AI), E-bikes, Smart Meter, E-buses, Smart devices |
| | [83] | Cloud technology, Internet of Everything (IoE), Sensor, Big Data |
| | [84] | Electric vehicle (EV), ICT, Smart Building, Smart Grid, Solar PV, Charging infrastructure |
| | [85] | Internet of Things (IoT), Smart Home, Smartphone, Smart Sensors, Wi-Fi, Home Energy Management System (HEMS), Smart home assistance |
| | [86] | Smart Grid |
| | [87] | ICT, Big Data, Real-time building performance app |
| 6 | [88] | Carbon footprint calculator |
| | [89] | ICT |
| | [11] | ICT, Smartphone, Feedback technology app |
| | [90] | Smart Grid, |
| | [49] | Smart Grid |
| | [91] | Electric vehicle (EV), Solar PV |
| 5 | [37] | Internet of Things (IoT), Smart Grid |
| | [92] | Energy Management System (EMS), Smart Meter |
| | [93] | ICT, Internet of Things (IoT), Smart Meter |
| | [94] | Building Energy Management System (BEMS), Electric vehicle (EV), Smart Grid |
| | [19] | Smart Mobility, Smart apps |
| 60 | Total Papers reviewed | |

**Table A2.** Classification of Technologies by Layer and Impact on Energy Consumption Behaviours.

| | LAYER | DEFINITION | TECHNOLOGY | NO. | NOTES ON ENERGY CONSUMPTION BEHAVIOURS |
|---|---|---|---|---|---|
| | ICT | Information and communications technology (ICT) is an extensional term for information technology (IT) that stresses the role of unified communications and the integration of telecommunications (telephone lines and wireless signals) and computers as well as necessary enterprise software, middleware, storage, and audio-visual that enable users to access, store, transmit, understand, and manipulate information. | ICT | 10 | Everything in the SSC framework is governed by ICT, which is connected via Wi-Fi. The SSC idea is that the more interconnected everything is within the ICT bandwidth, the more the users' data can be used to systematically administer a city into a smarter model. |
| | | | Total | 10 | |
| | NETWORK LAYER | A group of two or more computers or other electronic devices that are interconnected for exchanging data and sharing resources through a server route and connection | Wi-Fi | 6 | |
| | | | 5G | 1 | |
| | | | Beyond 5G (B5G) | 1 | |
| | | | Total | 10 | |
| ENERGY SYSTEM MANAGEMENT | SYSTEM MANAGEMENT | Management layer within Smart City that manages the systems such as the smart city infrastructure | Smart Grid | 21 | |
| | | | Building Energy Management System (BEMS) | 3 | influences occupants' behaviours by providing suggestions that help eliminate unnecessary heating and cooling. |
| | | | Energy Management System (EMS) | 2 | |
| | | | Home Energy Management System (HEMS) | 2 | HEMS brings up to 30% savings if householders value energy conservation over comfort. |
| | | | Advanced metering infrastructure (AMI) | 1 | A framework for automated, bilateral communication between a utility and consumer to make consumers more aware of their energy consumption. |
| | | | Smart Energy Management System | 1 | Utilises IoT and development tools to build sustainable solutions. |
| | | | Smart Thermal Management System | 1 | |
| | | | Renewable Energy System | 1 | The drive towards smart energy consumption is to transition into a renewable energy system that utilises smart technologies at the city management level. |
| | | | Smart Power Storage | 1 | |
| | | | Smart Power Generation | 1 | |
| | | | Smart Wind Power | 1 | |
| | | | Solar Thermal and Hydro | 1 | |
| | | | Smart environmental monitoring | 1 | |
| | | | Smart infrastructure | 2 | Smart infrastructure, enabled by technologies like IoT, offers numerous advantages, bringing serious cost savings and efficiencies. |
| | | | Charging infrastructure | 1 | Charging for smart mobile influences people to adopt eco-cars. |
| | | | Total | 40 | |

**Table A2.** *Cont.*

| | LAYER | | | DEFINITION | TECHNOLOGY | NO. | NOTES ON ENERGY CONSUMPTION BEHAVIOURS |
|---|---|---|---|---|---|---|---|
| TECHNOLOGY—TECHNOLOGY INTERACTION (HTI) | DATA AND SUPPORT LAYER | APPLICATION SUPPORT SERVICE | | The technological platform supports the IoT system and network with technology that supports functionalities, provides information to corresponding city applications and services, and enables integrated applications exchanging data via data centres and/or application support functionalities. | Fog computing | 2 | A setting that provides a space for gathering, processing, and preserving smart metering information before its transfer to the cloud. |
| | | | | | Edge computing | 2 | Contribute to a more sustainable and efficient management of energy consumption while also offering benefits in terms of system performance and security. |
| | | | | | Blockchain Technology | 3 | Enhance the security of smart home devices. |
| | | APPLICATION SUPPORT SERVER | | | Global Positioning System (GPS) | 3 | GPS tracks human data in smart cities and is installed in apps and smartphones to influence lower carbon travel. Micro-location GPS applications, with considerable accuracy, determine occupancy in real-time. |
| | | | | | Geographic Information Systems—GIS | 1 | Used for the construction of the digital model of urban ‘horizontal components’ such as urban networks, transport facilities and natural environment. |
| | | | | | Cognitive technology | 1 | Self-machine learning to compute human data. |
| | | DATA PROCESS SERVICE | | Data and file repositories, where data are created or retrieved | Cloud technology | 12 | Energy big data offer a new way to evaluate and comprehend individual energy use, where machine learning is widely used to predict energy consumption. |
| | | | | | Big Data | 10 | |
| | | | | | Big Data Analytics | 1 | |
| | | | | | Machine learning and Data mining | 1 | |
| | | | | | Total | 36 | |
| | SENSING LAYER | SENSING NERVOUS SYSTEM | INTERNET OF THINGS (IoT) | The Internet of Things (IoT) is a network of physical objects—“things”—embedded with sensors, software, and other technologies to connect to and exchange data with other devices and systems over the Internet. These “things” range from everyday household items to sophisticated industrial tools. | Internet of Things (IoT) | 17 | Sensors can learn how to adjust the temperature based on habits and according to occupancy through data. |
| | | | INTERNET OF EVERY-THING (IoE) | “Internet of Everything” (IoE) refers to Internet-connected devices and consumer products with enhanced digital features. It describes a world where billions of objects have sensors to detect, measure, and assess their status, all connected over public or private networks using standard and proprietary protocols. | Internet of Everything (IoE) | 3 | |
| | | | | | Total | 20 | |

**Table A2.** *Cont.*

| LAYER | | | DEFINITION | TECHNOLOGY | NO. | NOTES ON ENERGY CONSUMPTION BEHAVIOURS |
|---|---|---|---|---|---|---|
| TECHNOLOGY—TECHNOLOGY INTERACTION (HTI) | SENSING ORGAN | TERMINAL NODE | Devices that sense the natural environment where the SSC is located and the corresponding hard infrastructure and utilities. It provides the superior 'environment-detecting' ability and intelligence for monitoring and controlling the physical infrastructure within the system network | Integrated sensors in smart appliances | 1 | Smart appliances are connected via IoT sensors that can learn through data how to adjust the temperature based on habits and according to occupancy. |
| | | | | Robot Monitoring | 1 | Automating energy consumption behaviour through patterns. |
| | | | | Transponder | 1 | The core that makes traditional home appliances smart and collects data to inform users' habits. |
| | | | | CCTV | 4 | Monitor behaviour. |
| | | | | Smart Sensors | 12 | Enables IoT to measure energy consumption behaviour and give feedback to the users. |
| | | | | Real-time monitoring stations | 1 | Real-time monitoring allows facility managers to better manage and analyse the vast data gathered from their buildings. |
| | | | | Artificial Intelligence (AI) | 5 | Artificial intelligence is designed to emulate human abilities, and it is frequently placed in smart homes and programmed to automate behaviour. |
| | | | | Ubiquitous computing | 1 | Monitor behaviour. |
| | | | | Total | 26 | |
| | | | | Wireless mesh network | 1 | A communications network made up of radio nodes organised in a mesh topology. It can also be a form of wireless ad hoc network. |
| | | | | Wireless Sensor Network (WSN) | 1 | |
| | | | | Wi-SUN (Smart Utility Network) | 1 | Connects smart meters and other intelligent devices, the right communication network. |
| | | | | Sensor's network- soft sensing approach | 2 | Measures and computes data from smart sensors via network. |
| | | | | Near field communication (NFC) | 2 | It is a short-range wireless connectivity technology that lets NFC-enabled devices communicate with each other. |
| | | | | RFID | 4 | Occupancy sensors can be used for tracking occupants' patterns and estimate power usage in a day. |
| | | | | Unmanned Aerial Vehicles (UAV)—drones | 6 | Mainly used in smart cities for security purposes and smart traffic control. |
| | | | | Soft computing | 1 | Predicts energy consumption in a household through behavioural input |
| | | | | | 18 | |
| | | | | Total | 100 | |

**Table A2.** *Cont.*

| LAYER | | DEFINITION | TECHNOLOGY | NO. | NOTES ON ENERGY CONSUMPTION BEHAVIOURS |
|---|---|---|---|---|---|
| HUMAN–TECHNOLOGY INTERACTION (HTI) | PRODUCT | The type of SSC technologies people engage with, utilise, and use. | (a) Mobility | | |
| | | | Electric vehicle (EV) | 8 | More environmentally conscious people may opt for smart vehicles or smart travelling.<br>Smart mobility is one of the features of smart city technology and innovation. |
| | | | E-bikes | 7 | |
| | | | E-buses | 1 | |
| | | | Smart buses | 1 | |
| | | | Smart Car | 1 | |
| | | | Bicycle Sharing System (BSS) | 2 | |
| | | | Autonomous shuttles | 1 | |
| | | | | 21 | |
| | | | (b) Electronic | | |
| | | | Smart home assistance | 1 | Smart city technology is integrated with IoT features that connect smart devices. Home devices collect data regarding behaviour and energy consumption habits that users have more data on to save energy. |
| | | | Digital appliances | 1 | |
| | | | Smart gadgets | 1 | |
| | | | Display monitors | 1 | |
| | | | Interactive dashboards | 1 | |
| | | | Smartphones | 5 | |
| | | | Smart devices | 1 | |
| | | | Smart Plugs and Switches | 1 | |
| | | | Smart thermostat | 1 | |
| | | | Smart bulb | 1 | |
| | | | Smart Meter | 15 | Socioeconomic factors including education, social norms, age, and culture have a marked impact in the case of households. Second, the willingness of consumers to change their behaviour depends on their preferences concerning criteria such as price risk, volume risk, complexity, and loss of autonomy or privacy. For consumers to be engaged, their preferences must be met by personalised actions in the contract terms. |
| | | | Total | 29 | |
| | | | (c) Building | | |
| | | | Smart Building | 9 | They offer a more autonomous experience for end-users and provide efficient data to all stakeholders. With IoT sensors monitoring occupancy and reacting accordingly, a connected smart building can automatically respond to occupancy changes by turning off lights and adjusting HVAC systems to reduce consumption, accurately controlling how and where a building should manage its energy. |
| | | | Smart Home | 13 | |

**Table A2.** *Cont.*

| LAYER | | DEFINITION | TECHNOLOGY | NO. | NOTES ON ENERGY CONSUMPTION BEHAVIOURS |
|---|---|---|---|---|---|
| HUMAN–TECHNOLOGY INTERACTION (HTI) | PRODUCT | The type of SSC technologies people engage with, utilise, and use. | Zero Carbon Building (ZEB) | 3 | A net zero carbon building is highly energy efficient and powered by on-site and/or off-site renewable energy sources, most commonly associated with smart cities. |
| | | | Carbon footprint calculator | 2 | A website or app that people can input to keep track of their carbon footprint. Users can become more conscious of their behavioural impact on carbon. |
| | | | Smart appliances | 1 | Allows users to integrate and control many popular smart home technologies and smart devices that may influence energy consumption habits and control consumption. |
| | | | Smart lighting | 1 | |
| | | | Automatic meter reading (AMR) | 1 | |
| | | | Solar PV | 12 | |
| | | | High-energy heat pumps | 1 | |
| | | | LED low-power lighting | 1 | |
| | | | Solar water heaters | 1 | |
| | | | Thermal solar panels | 1 | |
| | | | Total | 46 | |
| | | | (d) Application | | |
| | | | Smart parking | 3 | Since smart devices are connected to smartphones via Wi-Fi, many apps are designed for users to explore their energy feedback through either their energy providers or install smart technologies that integrate smart features into their homes. |
| | | | Smart traffic | 3 | |
| | | | Smart transport | 1 | |
| | | | Smart mobility | 2 | |
| | | | E-deliveries | 1 | |
| | | | E-governance | 1 | |
| | | | Email | 1 | |
| | | | Clickstream | 1 | |
| | | | Smartphone app | 2 | |
| | | | Social media | 1 | |
| | | | Feedback technology app | 1 | |
| | | | Service Oriented Architecture (SOA) | 1 | |
| | | | Web based energy app | 1 | |
| | | | Real-time performance app | 1 | |
| | | | Smart apps | 1 | |
| | | | | 20 | |
| | | | Total | 116 | |

## References


1. Yigitcanlar, T.; Kamruzzaman, M. Does smart city policy lead to sustainability of cities? *Land Use Policy* **2018**, *73*, 49–58. [CrossRef]
2. Mora, L.; Deakin, M.; Zhang, X.; Batty, M.; de Jong, M.; Santi, P.; Appio, F.P. Assembling Sustainable Smart City Transitions: An Interdisciplinary Theoretical Perspective. *J. Urban Technol.* **2021**, *28*, 1–27. [CrossRef]
3. Cai, M.; Kassens-Noor, E.; Zhao, Z.; Colbry, D. Are smart cities more sustainable? An exploratory study of 103 U.S. cities. *J. Clean. Prod.* **2023**, *416*, 137986. [CrossRef]
4. Sang, Z.; Li, K. ITU-T standardisation activities on smart sustainable cities. *IET Smart Cities* **2019**, *1*, 3–9. [CrossRef]
5. Feng, L. City Brain, a New Architecture of Smart City Based on the Internet Brain. In Proceedings of the 2018 IEEE 22nd International Conference on Computer Supported Cooperative Work in Design, Nanjing, China, 9–11 May 2018; IEEE: Piscataway, NJ, USA, 2018. [CrossRef]
6. Stripple, J.; Bulkeley, H. Towards a material politics of socio-technical transitions: Navigating decarbonisation pathways in Malmö. *Political Geogr.* **2019**, *72*, 52–63. [CrossRef]
7. Becker, J.; Chasin, F.; Rosemann, M.; Beverungen, D.; Priefer, J.; Brocke, J.V.; Matzner, M.; Ortega, A.d.R.; Resinas, M.; Santoro, F.; et al. City 5.0: Citizen involvement in the design of future cities. *Electron. Mark.* **2023**, *33*, 10. [CrossRef]
8. Xu, A.; Wang, W.; Zhu, Y. Does smart city pilot policy reduce $CO_2$ emissions from industrial firms? Insights from China. *J. Innov. Knowl.* **2023**, *8*, 100367. [CrossRef]
9. Goh, C.S.; Chong, H.-Y. Opportunities in the Sustainable Built Environment: Perspectives on Human-Centric Approaches. *Energies* **2023**, *16*, 1301. [CrossRef]
10. Geels, F.W.; Schwanen, T.; Sorrell, S.; Jenkins, K.; Sovacool, B.K. Reducing energy demand through low carbon innovation: A sociotechnical transitions perspective and thirteen research debates. *Energy Res. Soc. Sci.* **2018**, *40*, 23–35. [CrossRef]
11. Khansari, N.; Aronson, Z.H.; Mostashari, A.; Mansouri, M. Influence of urban information availability on household energy consumption. *Int. J. Syst. Syst. Eng.* **2015**, *6*, 253–272. [CrossRef]
12. Abrahamse, W.; Steg, L.; Vlek, C.; Rothengatter, T. A review of intervention studies aimed at household energy conservation. *J. Environ. Psychol.* **2005**, *25*, 273–291. [CrossRef]
13. Bandura, A. Social cognitive theory: An agentic perspective. *Annu. Rev. Psychol.* **2001**, *52*, 1–26. [CrossRef]
14. Druckman, A.; Jackson, T. Understanding Households as Drivers of Carbon Emissions. In *Taking Stock of Industrial Ecology*; Clift, R., Druckman, A., Eds.; Springer International Publishing: Cham, Switzerland, 2016; pp. 181–203. [CrossRef]
15. Preston, S.; Mazhar, M.U.; Bull, R. Citizen engagement for co-creating low carbon smart cities: Practical lessons from nottingham city council in the uk. *Energies* **2020**, *13*, 6615. [CrossRef]
16. Bibri, S.E.; Krogstie, J. Environmentally data-driven smart sustainable cities: Applied innovative solutions for energy efficiency, pollution reduction, and urban metabolism. *Energy Inform.* **2020**, *3*, 29. [CrossRef]
17. Komninos, N.; Panori, A.; Kakderi, C. The Smart City Ontology 2.0: Assessing the Components and Interdependencies of City Smartness. *Preprints* **2021**, *10*, 2021080101. [CrossRef]
18. Ringenson, T.; Eriksson, E.; Börjesson Rivera, M.; Wangel, J. The Limits of the Smart Sustainable City. In Proceedings of the 2017 Workshop on Computing within Limits, Santa Barbara, CA, USA, 22–24 June 2017; Association for Computing Machinery: New York, NY, USA, 2017; pp. 3–9. [CrossRef]
19. Kramers, A.; Höjer, M.; Lövehagen, N.; Wangel, J. Smart sustainable cities—Exploring ICT solutions for reduced energy use in cities. *Environ. Model. Softw.* **2014**, *56*, 52–62. [CrossRef]
20. Joss, S.; Sengers, F.; Schraven, D.; Caprotti, F.; Dayot, Y. The Smart City as Global Discourse: Storylines and Critical Junctures across 27 Cities. *J. Urban Technol.* **2019**, *26*, 3–34. [CrossRef]
21. Israilidis, J.; Odusanya, K.; Mazhar, M.U. Exploring knowledge management perspectives in smart city research: A review and future research agenda. *Int. J. Inf. Manag.* **2021**, *56*, 101989. [CrossRef]
22. Visvizi, A.L.; Miltiadis, D. Rescaling and refocusing smart cities research: From mega cities to smart villages. *J. Sci. Technol. Policy Manag.* **2018**, *9*, 134–145. [CrossRef]
23. Ben Yahia, N.; Eljaoued, W.; Ben Saoud, N.B.; Colomo-Palacios, R. Towards sustainable collaborative networks for smart cities co-governance. *Int. J. Inf. Manag.* **2021**, *56*, 102037. [CrossRef]
24. Tranfield, D.; Denyer, D.; Smart, P. Towards a methodology for developing evidence-informed management knowledge by means of systematic review. *Br. J. Manag.* **2003**, *14*, 207–222. [CrossRef]
25. Patorniti, N.P.; Stevens, N.J.; Salmon, P.M. A sociotechnical systems approach to understand complex urban systems: A global transdisciplinary perspective. *Hum. Factors Ergon. Manuf.* **2018**, *28*, 281–296. [CrossRef]
26. Sintov, N.D.; Eschultz, P.W. Unlocking the potential of smart grid technologies with behavioral science. *Front. Psychol.* **2015**, *6*, 410. [CrossRef]
27. Gardner, G.T.; Stern, P.C. The most effective actions U.S. households can take to curb climate change. *Environment* **2008**, *50*, 12–25. [CrossRef]
28. Fang, X.; Goette, L.; Rockenbach, B.; Sutter, M.; Tiefenbeck, V.; Schoeb, S.; Staake, T. Complementarities in behavioral interventions: Evidence from a field experiment on resource conservation. *J. Public Econ.* **2023**, *228*, 105028. [CrossRef]
29. Becker, S.; Demski, C.; Smith, W.; Pidgeon, N. Public perceptions of heat decarbonization in Great Britain. *Wiley Interdiscip. Rev. Energy Environ.* **2023**, *12*, e492. [CrossRef]

30. Wei, Y.; Xia, L.; Pan, S.; Wu, J.; Zhang, X.; Han, M.; Zhang, W.; Xie, J.; Li, Q. Prediction of occupancy level and energy consumption in office building using blind system identification and neural networks. *Appl. Energy* **2019**, *240*, 276–294. [CrossRef]
31. Wei, J.; Zhang, L.; Yang, R.; Song, M. A new perspective to promote sustainable low-carbon consumption: The influence of informational incentive and social influence. *J. Environ. Manag.* **2023**, *327*, 116848. [CrossRef]
32. Agarwal, R.; Garg, M.; Tejaswini, D.; Garg, V.; Srivastava, P.; Mathur, J.; Gupta, R. A review of residential energy feedback studies. *Energy Build.* **2023**, *290*, 113071. [CrossRef]
33. Liu, Z.; Zhang, X.; Sun, Y.; Zhou, Y. Advanced controls on energy reliability, flexibility and occupant-centric control for smart and energy-efficient buildings. *Energy Build.* **2023**, *297*, 113436. [CrossRef]
34. Jin, X.; Zhang, C.; Xiao, F.; Li, A.; Miller, C. A review and reflection on open datasets of city-level building energy use and their applications. *Energy Build.* **2023**, *285*, 112911. [CrossRef]
35. Khatoun, R.; Zeadally, S. Smart cities: Concepts, architectures, research opportunities. *Commun. ACM* **2016**, *59*, 46–57. [CrossRef]
36. Serrano-Hernandez, A.; Ballano, A.; Faulin, J. Selecting Freight Transportation Modes in Last-Mile Urban Distribution in Pamplona (Spain): An Option for Drone Delivery in Smart Cities. *Energies* **2021**, *14*, 4748. [CrossRef]
37. Calvez, P.; Soulier, E. Sustainable assemblage for energy (SAE) inside intelligent urban areas: How massive heterogeneous data could help to reduce energy footprints and promote sustainable practices and an ecological transition. In Proceedings of the 2014 IEEE International Conference on Big Data, Washington, DC, USA, 27–30 October 2014; IEEE: Piscataway, NJ, USA, 2015. [CrossRef]
38. de Souza, J.T.; de Francisco, A.C.; Piekarski, C.M.; Prado, G.F.D. Data Mining and Machine Learning to Promote Smart Cities: A Systematic Review from 2000 to 2018. *Sustainability* **2019**, *11*, 1077. [CrossRef]
39. Buchanan, K.; Russo, R.; Anderson, B. Feeding back about eco-feedback: How do consumers use and respond to energy monitors? *Energy Policy* **2014**, *73*, 138–146. [CrossRef]
40. Lindner, R.; Daimer, S.; Beckert, B.; Heyen, N.; Koehler, J.; Teufel, B.; Warnke, P.; Wydra, S. Addressing directionality: Orientation failure and the systems of innovation heuristic. Towards reflexive governance. *Fraunhofer ISI* **2016**, 52. [CrossRef]
41. Trincado, E.; Sánchez-Bayón, A.; Vindel, J.M. The European Union Green Deal: Clean Energy Wellbeing Opportunities and the Risk of the Jevons Paradox. *Energies* **2021**, *14*, 4148. [CrossRef]
42. D'amico, G.; L'abbate, P.; Liao, W.; Yigitcanlar, T.; Ioppolo, G. Understanding Sensor Cities: Insights from Technology Giant Company Driven Smart Urbanism Practices. *Sensors* **2020**, *20*, 4391. [CrossRef]
43. Corsini, F.; Certomà, C.; Dyer, M.; Frey, M. Participatory energy: Research, imaginaries and practices on people' contribute to energy systems in the smart city. *Technol. Forecast. Soc. Chang.* **2019**, *142*, 322–332. [CrossRef]
44. Yang, Z.; Li, L.; Yuan, H.; Dong, Y.; Liu, K.; Lan, L.; Lin, W.; Jin, K.; Zhu, C.; Chai, C.; et al. Evaluation of Smart Energy Management Systems and Novel UV-Oriented Solution for Integration, Resilience, Inclusiveness and Sustainability. In Proceedings of the 2020 5th International Conference on Universal Village (UV), Boston, MA, USA, 24–27 October 2020; IEEE: Piscataway, NJ, USA, 2021; pp. 1–49. [CrossRef]
45. Kumar, P.; Caggiano, H.; Shwom, R.; Felder, F.A.; Andrews, C.J. Saving from home! How income, efficiency, and curtailment behaviors shape energy consumption dynamics in US households? *Energy* **2023**, *271*, 126988. [CrossRef]
46. Bisello, A. Assessing Multiple Benefits of Housing Regeneration and Smart City Development: The European Project SINFONIA. *Sustainability* **2020**, *12*, 8038. [CrossRef]
47. Alsamhi, S.; Afghah, F.; Sahal, R.; Hawbani, A.; Al-Qaness, M.A.; Lee, B.; Guizani, M. Green internet of things using UAVs in B5G networks: A review of applications and strategies. *Ad Hoc Netw.* **2021**, *117*, 102505. [CrossRef]
48. Almeida, L.M.M.C.E.; Tam, V.W.Y.; Le, K.N. Quantification of the energy use due to occupant behaviour collected in surveys: A case study of a green and non-green building. *J. Build. Perform. Simul.* **2020**, *13*, 777–803. [CrossRef]
49. Solacolu, H.S.A. Real-time ethics—A technology enabled paradigm of everyday ethics in smart cities: Shifting sustainability responsibilities through citizen empowerment. In Proceedings of the 2015 IEEE International Symposium on Technology and Society (ISTAS), Dublin, Ireland, 11–12 November 2015; IEEE: Piscataway, NJ, USA, 2016; pp. 1–5. [CrossRef]
50. Cao, S.; Chen, Y.; Cheng, G.; Du, F.; Gao, W.; He, Z.; Li, S.; Lun, S.; Ma, H.; Su, Q.; et al. Preliminary Study on Evaluation of Smart-CitiesTechnologies and Proposed UV Lifestyles. In Proceedings of the 2018 4th International Conference on Universal Village (UV), Boston, MA, USA, 21–24 October 2018; IEEE: Piscataway, NJ, USA, 2019. [CrossRef]
51. Razaghi, M.; Finger, M. Smart Governance for Smart Cities. *Proc. IEEE* **2018**, *106*, 680–689. [CrossRef]
52. Mark, R.; Anya, G. Ethics of Using Smart City AI and Big Data: The Case of Four Large European Cities. *ORBIT J.* **2019**, *2*, 1–36. [CrossRef]
53. De Dominicis, S.; Sokoloski, R.; Jaeger, C.M.; Schultz, P.W. Making the smart meter social promotes long-term energy conservation. *Palgrave Commun.* **2019**, *5*, 51. [CrossRef]
54. Morton, A.; Reeves, A.; Bull, R.; Preston, S. Empowering and Engaging European building users for energy efficiency. *Energy Res. Soc. Sci.* **2020**, *70*, 101772. [CrossRef]
55. El Hafdaoui, H.; Khallaayoun, A.; Ouazzani, K. Activity and efficiency of the building sector in Morocco: A review of status and measures in Ifrane. *AIMS Energy* **2023**, *11*, 454–485. [CrossRef]
56. Mateus, R.A.S.; Oliveira, T.; Neves, C. Sustainable technology: Antecedents and outcomes of households' adoption. *Energy Build.* **2023**, *284*, 112846. [CrossRef]

57. Taneja, A.; Rani, S.; Herencsar, N. Energy aware solution for IRS-aided UAV communication in 6G wireless networks. *Sustain. Energy Technol. Assess.* **2023**, *58*, 103318. [CrossRef]
58. Shanmugapriya, I. A Survey on Energy Management Evolution and Techniques for Green IoT Environment. In *Proceedings of the Fourth International Conference on Communication, Computing and Electronics Systems: ICCCES 2022*; Tavares, J.M.R.S., Chandrasekar, V., Bindhu, V., Eds.; Springer: Singapore, 2023; pp. 155–165. [CrossRef]
59. Gumz, J.; Fettermann, D.C.; Sant'Anna, M.O.; Tortorella, G.L. Social Influence as a Major Factor in Smart Meters' Acceptance: Findings from Brazil. *Results Eng.* **2022**, *15*, 100510. [CrossRef]
60. Imran; Iqbal, N.; Kim, D.H. IoT Task Management Mechanism Based on Predictive Optimization for Efficient Energy Consumption in Smart Residential Buildings. *Energy Build.* **2022**, *257*, 111762. [CrossRef]
61. Mostofi, H. The frequency use and the modal shift to ICT-based mobility services. *Resour. Environ. Sustain.* **2022**, *9*, 100076. [CrossRef]
62. Kim, N.; Yang, S. Characteristics of Conceptually Related Smart Cities (CRSCs) Services from the Perspective of Sustainability. *Sustainability* **2021**, *13*, 3334. [CrossRef]
63. Seferlis, P.; Varbanov, P.S.; Papadopoulos, A.I.; Chin, H.H.; Klemeš, J.J. Sustainable design, integration, and operation for energy high-performance process systems. *Energy* **2021**, *224*, 120158. [CrossRef]
64. Barr, S.; Lampkin, S.; Dawkins, L.; Williamson, D. Smart cities and behavioural change: (Un)sustainable mobilities in the neo-liberal city. *Geoforum* **2021**, *125*, 149. [CrossRef]
65. Nižetić, S.; Šolić, P.; González-de-Artaza, D.L.-d.I.; Patrono, L. Internet of Things (IoT): Opportunities, issues and challenges towards a smart and sustainable future. *J. Clean. Prod.* **2020**, *274*, 122877. [CrossRef] [PubMed]
66. Przywojska, J.; Podgórniak-Krzykacz, A. A comprehensive approach: Inclusive, smart and green urban development. *Probl. Sustain. Dev./Probl. Ekorozwoju* **2020**, *15*, 149–160. [CrossRef]
67. Oliveira, T.A.; Gabrich, Y.B.; Ramalhinho, H.; Oliver, M.; Cohen, M.W.; Ochi, L.S.; Gueye, S.; Protti, F.; Pinto, A.A.; Ferreira, D.V.M.; et al. Mobility, Citizens, Innovation and Technology in Digital and Smart Cities. *Future Internet* **2020**, *12*, 22. [CrossRef]
68. Balali, V.; Fathi, S.; Aliasgari, M. Vector Maps Mobile Application for Sustainable Eco-Driving Transportation Route Selection. *Sustainability* **2020**, *12*, 5584. [CrossRef]
69. Alsamhi, S.H.; Ma, O.; Ansari, M.S.; Almalki, F.A. Survey on Collaborative Smart Drones and Internet of Things for Improving Smartness of Smart Cities. *IEEE Access* **2019**, *7*, 128125–128152. [CrossRef]
70. Nižetić, S.; Djilali, N.; Papadopoulos, A.; Rodrigues, J.J. Smart technologies for promotion of energy efficiency, utilization of sustainable resources and waste management. *J. Clean. Prod.* **2019**, *231*, 565–591. [CrossRef]
71. O'dwyer, E.; Pan, I.; Acha, S.; Shah, N. Smart energy systems for sustainable smart cities: Current developments, trends and future directions. *Appl. Energy* **2019**, *237*, 581–597. [CrossRef]
72. Emeakaroha, A.; Ang, C.; Yan, Y. Challenges in Improving Energy Efficiency in a University Campus Through the Application of Persuasive Technology and Smart Sensors. *Challenges* **2012**, *3*, 290–318. [CrossRef]
73. Médard de Chardon, C. The contradictions of bike-share benefits, purposes and outcomes. *Transp. Res. Part A Policy Pract.* **2019**, *121*, 401–419. [CrossRef]
74. Sodiq, A.; Baloch, A.A.; Khan, S.A.; Sezer, N.; Mahmoud, S.; Jama, M.; Abdelaal, A. Towards modern sustainable cities: Review of sustainability principles and trends. *J. Clean. Prod.* **2019**, *227*, 972–1001. [CrossRef]
75. van den Buuse, D.; Kolk, A. An exploration of smart city approaches by international ICT firms. *Technol. Forecast. Soc. Chang.* **2019**, *142*, 220–234. [CrossRef]
76. Deakin, M.; Reid, A. Smart cities: Under-gridding the sustainability of city-districts as energy efficient-low carbon zones. *J. Clean. Prod.* **2018**, *173*, 39–48. [CrossRef]
77. Moghadam, S.T.; Toniolo, J.; Mutani, G.; Lombardi, P. A GIS-statistical approach for assessing built environment energy use at urban scale. *Sustain. Cities Soc.* **2018**, *37*, 70–84. [CrossRef]
78. Kumar, T.; Mani, M. Life Cycle Assessment (LCA) to Assess Energy Neutrality in Occupancy Sensors. In *Research into Design for Communities*; Springer: Berlin/Heidelberg, Germany, 2017; Volume 2, pp. 105–166. [CrossRef]
79. Mosannenzadeh, F.; Bisello, A.; Vaccaro, R.; D'Alonzo, V.; Hunter, G.W.; Vettorato, D. Smart energy city development: A story told by urban planners. *Cities* **2017**, *64*, 54–65. [CrossRef]
80. Chalal, M.L.; Benachir, M.; White, M.; Shahtahmassebi, G.; Cumberbatch, M.; Shrahily, R. The impact of the UK household life-cycle transitions on the electricity and gas usage patterns. *Renew. Sustain. Energy Rev.* **2017**, *80*, 505–518. [CrossRef]
81. March, H.; Morote, Á.-F.; Rico, A.-M.; Saurí, D. Household Smart Water Metering in Spain: Insights from the Experience of Remote Meter Reading in Alicante. *Sustainability* **2017**, *9*, 582. [CrossRef]
82. Tan, H.; Yuan, Y.; Zhong, S.; Yang, Y. Joint Rebalancing and Charging for Shared Electric Micromobility Vehicles with Energy-informed Demand. In Proceedings of the 32nd ACM International Conference on Information and Knowledge Management, Birmingham, UK, 21–25 October 2023; pp. 2392–2401. [CrossRef]
83. Bull, R.; Azennoud, M. Smart citizens for smart cities: Participating in the future. *Proc. Inst. Civ. Eng. Energy* **2016**, *169*, 93–101. [CrossRef]
84. Granier, H.K.B. Citizen Co-designed and Co-produced Smart City: Japanese Smart City Projects. In Proceedings of the 9th International Conference on Theory and Practice of Electronic Governance, Montevideo, Uruguay, 1–3 March 2016; Association for Computing Machinery: New York, NY, USA, 2016; pp. 240–249. [CrossRef]

85. Matsui, K. Information provision system in a home energy and comfort management system for energy conservation. In Proceedings of the 2016 International Symposium on Networks, Computers and Communications (ISNCC), Yasmine Hammamet, Tunisia, 11–13 May 2016; IEEE: Piscataway, NJ, USA, 2016; pp. 1–6. [CrossRef]
86. Schiller, F. Urban transitions: Scaling complex cities down to human size. *J. Clean. Prod.* **2016**, *112*, 4273–4282. [CrossRef]
87. Stangaciu, C.S.; Micea, M.V.; Cretu, V.I. Energy efficiency in real-time systems: A brief overview. In Proceedings of the 2013 IEEE 8th International Symposium on Applied Computational Intelligence and Informatics (SACI), Timisoara, Romania, 23–25 May 2013; IEEE: Piscataway, NJ, USA, 2013; pp. 275–280. [CrossRef]
88. West, S.E.; Owen, A.; Axelsson, K.; West, C.D. Evaluating the Use of a Carbon Footprint Calculator: Communicating Impacts of Consumption at Household Level and Exploring Mitigation Options. *J. Ind. Ecol.* **2015**, *20*, 396–409. [CrossRef]
89. Kammerlander, M.; Schanes, K.; Hartwig, F.; Jäger, J.; Omann, I.; O'Keeffe, M. A resource-efficient and sufficient future mobility system for improved well-being in Europe. *Eur. J. Futures Res.* **2015**, *3*, 8. [CrossRef]
90. Mantilla, R.F.; Nieto, L.A.; Lastra, J.L.M. Parameters affecting the energy performance of the transport sector in smart cities. In Proceedings of the SMARTGREENS 2015-4th International Conference on Smart Cities and Green ICT Systems, Proceedings, Lisbon, Portugal, 20–22 May 2015; SCITEPRESS: Setúbal, Portugal, 2015; pp. 83–88. [CrossRef]
91. Vassileva, I.; Thygesen, R.; Campillo, J.; Schwede, S. From Goals to Action: The Efforts for Increasing Energy Efficiency and Integration of Renewable Sources in Eskilstuna, Sweden. *Resources* **2015**, *4*, 548–565. [CrossRef]
92. McGibbon, C.; Ophoff, J.; Van Belle, J.-P. Our building is smarter than your building: The use of competitive rivalry to reduce energy consumption and linked carbon footprint. *Knowl. Manag. E-Learn.* **2014**, *6*, 464–471. [CrossRef]
93. Tanaka, R.; Schmidt, M.; Åhlund, C.; Takamatsu, Y. An energy awareness study in a Smart City lessons learned. In Proceedings of the 2014 IEEE Ninth International Conference on Intelligent Sensors, Sensor Networks and Information Processing (ISSNIP), Singapore, 21–24 April 2014; IEEE: Piscataway, NJ, USA, 2014; pp. 1–4. [CrossRef]
94. Kii, M.; Akimoto, K.; Doi, K. Measuring the impact of urban policies on transportation energy saving using a land use-transport model. *IATSS Res.* **2014**, *37*, 98–109. [CrossRef]