sustainability

MDPI

Review

Potential Applications of 5G Network Technology for Climate Change Control: A Scoping Review of Singapore

Ghasan Fahim Huseien and Kwok Wei Shah *

Department of the Build Environment, School of Design and Environment, National University of Singapore, Singapore 117566, Singapore; bdggfh@nus.edu.sg
* Correspondence: bdgskw@nus.edu.sg; Tel.: +65-9366-6795

Abstract: Climate change is one of the most challenging problems that humanity has ever faced. With the rapid development in technology, a key feature of 5G networks is the increased level of connectivity between everyday objects, facilitated by faster internet speeds with smart facilities indicative of the forthcoming 5G-driven revolution in Internet of Things (IoT). This study revisited the benefits of 5G network technologies to enhance the efficiency of the smart city and minimize climate change impacts in Singapore, thus creating a clean environment for healthy living. Results revealed that the smart management of energy, wastes, water resources, agricultures, risk factors, and the economy adopted in Singapore can remarkably contribute to reducing climate change, thus attaining the sustainability goals. Hence, future studies on cost-effective design and implementation are essential to increase the focus on the smart city concept globally.

Keywords: 5G technology; climate change; energy management; smart cities; sustainability; wastes management; water resources management

Citation: Huseien, G.F.; Shah, K.W. Potential Applications of 5G Network Technology for Climate Change Control: A Scoping Review of Singapore. *Sustainability* **2021**, *13*, 9720. https://doi.org/10.3390/su13179720

Academic Editors: Md Younus and Dalia Štreimikienė

Received: 13 June 2021
Accepted: 23 August 2021
Published: 30 August 2021

1. Introduction

Currently, the entire planet is at risk due to continual climate change [1–3]. The recorded increase in average temperature across the world in the past hundred years, and the associated changes attributed to this, are known as global warming. Many scientists are convinced by the published evidence that this change is anthropogenic and resulted from the elevated emission levels of global greenhouse gases (GHGs) [4,5]. Gases such as water vapor, carbon dioxide, methane, nitrous oxide, and ozone are responsible for the absorption and emission of thermal radiation. These changes in the relative quantities of the GHGs induce a proportional change in the amount of preserved solar energy. Presently, the accepted indicator for global warming is the sustained rise in the mean temperature worldwide. This definition is designed to account for the fact that there may be some localized exceptions to this rise. For example, there may be cooling experienced in a region while the global temperature may increase altogether, hence the need for average temperature. A key concern with the GHGs trapping of more heat in the atmosphere is that it affects both climate and short scale weather patterns. Consequently, it results in greater numbers of adverse weather events such as storms, heat waves, cold snaps, droughts, and fires [6]. Climate-related risks to health, livelihoods, food security, water supply, human safety, and economic growth are projected to increase with global warming of 1.5 °C [7] and further increase further at 2 °C, as shown in Figure 1. In addition, the risks to global aggregated economic growth due to the climate change impacts are projected to be lower at 1.5 °C than at 2 °C by the end of this century.

Carbon dioxide has the most substantial effect on global warming [8]. Although it was once assumed to have an ~100 year lifespan in the atmosphere, careful studies revealed that the situation is far worse, with three-quarters of the gas expected to remain for a time in the region of up to ~1000 years, with the remainder lasting for an indefinite period of time [9]. It was indicated that the present impacts of humanity on the atmosphere can certainly cause a long term problem [10]. Carbon dioxide is released when oil, coal, and other fossil fuels are burnt for the energy we use to power our homes, cars, and smartphones. By lessening its usage, we can curb our own contribution to climate change while saving money. The first challenge is eliminating the burning of coal, oil, and, eventually, natural gas. Oil is the lubricant of the global economy as it is hidden inside such ubiquitous items as plastic and corn, fundamental to the transportation of both consumers and goods. Coal is the substrate, supplying roughly half of the electricity worldwide, a percentage that is likely to grow according to the International Energy Agency (IEA). In fact, buildings contribute up to 43% of all the greenhouse gas emissions worldwide [11], even though investing in thicker insulation and other cost-effective as well as temperature-regulating strategies can save money in the long run. Investment in new infrastructures, or radical upgradation of the existing highways and transmission lines, may help to reduce greenhouse gas emissions, yielding economic growth in the developing countries.

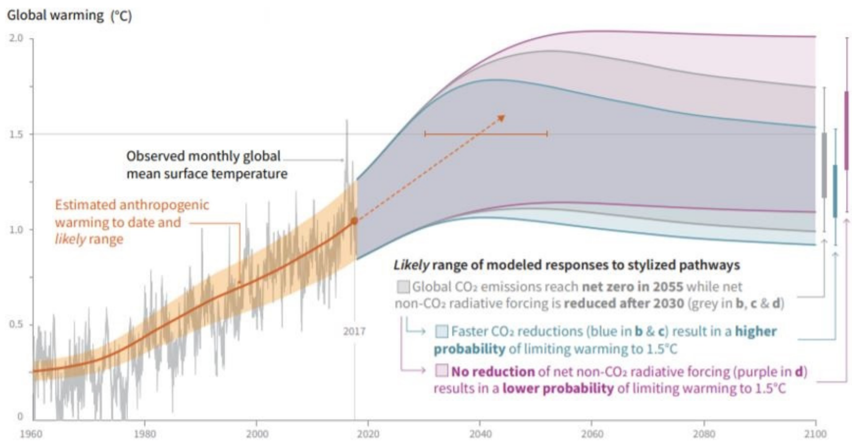

Figure 1. Recorded and expected global warming from 1960 to 2100 [7].

Nations across the globe have kept very high targets to reducing their GHG discharges [12,13]. In order to meet these goals, considerable reductions in city energy usage is required. At a global scale, urban communities represent over half (55%) of the population, which is predicted to reach 68% by the middle of this century [14]. Urban areas claim ownership of the highest levels of energy use, gas emission, and also the largest local economy. As such, it is crucial for urban areas to reduce their consumption and utilize renewable sources wherever available to reduce their gas discharge levels. Smart cities often utilize digital sensors to measure and transmit data about the levels of GHGs in the city at that moment, as a means of tackling them [15]. The efficacy of such a system is thus reliant on the network used to collate and analyze the data collected as an extant network. The mobile telecommunications networks offer a convenient solution to this desire, as their pre-existence has the clear benefit of reducing costs compared to the design and implementation of a novel system. It is recognized that smart cities will certainly act as the key players meeting these ambitious targets [16,17]. In this study, we focused primarily on the potential applications of 5G network technology to control climate change in Singapore. In addition, a clear overview of the sustainability benefits of introducing 5G technology compatible smart cities, buildings, and farms in all aspects of urbanization is provided. Herein, the main purpose is to tackle the negative outcomes associated with anthropogenic climate change, with a particular focus on the contributions that are best made by the telecoms network operators.

Climate change is one of the most challenging problems that humanity has ever faced. Presently, hundreds of millions of lives, innumerable species, entire ecosystems, health, economy, and the future habitability of this planet are at risk. Fortunately, climate change is solvable, we just need to wisely exploit the existing technologies and sciences. Climate change mitigation is a pressing international need in which many management actions are required. The development of 5G technology has been largely driven by smart mobile devices and advanced communication technologies. It may thus serve as a technical enabler for a whole new range of business opportunities, energy, and facilities management, together with industrial applications. Moreover, it may enable different devices to work together seamlessly. Definitely, the 5G cellular network technology is expected to revolutionize the global industries with profound effects on the savings of energy, waste generation and recycling, and water resources management, thus reducing the climate change impacts.

Motivated by the requirement of the smart cities to control climate change and reduce their global greenhouse emission, this paper aimed to guide the stakeholders in the infrastructure and construction industry to adopt a better path with the proper use the 5G technology to address the climate change issues. In addition, it may inspire the researchers' thinking in the technology industry for future advancement of Singapore through collaboration trends of different industries. This paper also analyzed how 5G networks can help to overcome the challenges posed by the current wireless networks in implementing smart energy, water resource, risk, economic, and waste management solutions. Figure 2 illustrates the potential applications of 5G technology to reduce greenhouse gas emissions and climate change impacts. It discusses climate change, the advantages of 5G networks, and the main drivers of smart management. First, various climate change risk factors and various benefits of 5G networks for smart management are explored. Finally, the paper is concluded followed by some recommendations for further research and development within this field.

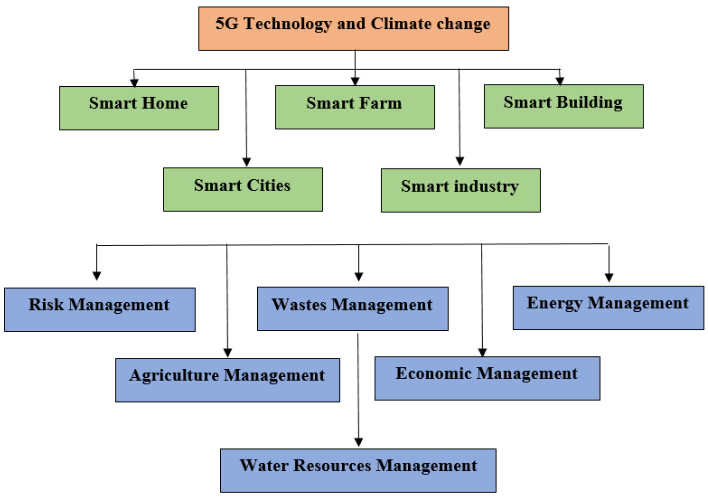

Figure 2. Applications of 5G technology for reducing the climate change impacts.

2. Climate Change Risk Factors

Climate change has several implications for the environment and public health. It has been inferred that the rise in the sea level will adversely affect millions of lives [18]. Higher concentrations of carbon dioxide are due to the excessive use of fertilizers for increasing crop yields. In fact, increases in the number of chemicals used have considerable economic and environmental consequences, especially the water table beyond their natural state [19]. Problems related to pest and disease control in the agricultural settings can affect the moisture–temperature balance [20]. Generally, it is recognized that both temperature and an appropriate level of moisture can overcome such a problem. A rise in the global average temperature implies that equatorially confined problems are expected to be seen more regularly further to the north and south. In short, climate change is associated with the (i) variability of rainfall patterns; (ii) changes in water levels in the lakes, rivers, seas, ponds, streams, and groundwater; (iii) frequency of storms and droughts; (iv) increased desert encroachment; (v) excessive heat. In fact, all of these have serious implications on the environment and public health.

In the United States, a government report shows that the climate is constantly changing, wherein further human activities will lead to many more changes. These changes will affect the sea levels, drought frequency, severe precipitation, and so forth. The Climate Science Special Report was created by a United States government organization for coordinating and integrating the federal research data on the global environment changes and their implications for the society. It also laid out the current state of science relating to climate change and its physical effects [21]. This report has assimilated numerous data on the rise of surface water level; atmospheric and oceanic temperatures; melting glaciers; diminishing snow cover; shrinking sea ice; rising sea levels; ocean acidification; increasing intensity and frequency of rainfall, hurricanes, heat waves, wildfires, and drought. It meticulously outlined how these effects can largely be traced back to human activities and associated emissions of potential GHGs as well as particles. Underlying the report is a broad scientific consensus which indicated that the farther and faster the Earth system is pushed toward more changes, the greater the risk is of unanticipated effects wherein some of them are potentially large and irreversible. It is expected that drought may plague the western United States for decades to come as well as Atlantic and Pacific hurricanes that could be even more violent [22]. Briefly, the report showed that our current emission trajectories may bring our planet into a very different climate state than it is today, with profound effects on the United States.

In many regions of the European countries, extreme weather and climate-related hazards such as heat waves, floods, and droughts will become more frequent and intense. This will have adverse impacts on ecosystems, economic sectors, and human health. Therefore, the risks minimization due to global climate change requires various targeted actions for adapting to such climate change-related impacts in addition to the remedial measure to reduce the GHG emissions. Adaptation must be tailored to the specific circumstances in different regions and cities of Europe. Climate change affects the agricultural systems in complex ways. In fact, the increase in the atmospheric CO_2 concentrations, temperatures, and changes in the precipitation patterns including the drought conditions can significantly affect the quantity, quality, and stability of food production. Although the food security in Europe is not expected to be at risk, the cascading impacts of climate change from outside Europe may further affect the agricultural income and price levels in Europe due to the alterations of trade patterns [23].

Climate change has already affected the conditions in Singapore with a mean temperature rise from 26.6 °C to 27.7 °C during 1972–2014 [24]. Sea levels have also shown annual increases of 1.2–1.7 mm in an equal timeframe (1975–2009). Increased annual rainfall has lately became a grave concern, wherein a rise from 2192 mm to 2727 mm across the span 1980–2014 has been observed. The north of Singapore in 2001 witnessed the impact of the first ever equatorial typhoon, *Vamei*, causing widespread localized flooding. The opinions about this typhoon are divided on the likelihood of repetition. The low altitude nature of the city state ensures that rising sea levels present the greatest threat to its future, with 30% of the city lying less than 5 m from the waterline and much of the rest within 15 m. More frequent changes in the local weather patterns can also hamper efforts of supplying potable water, as both droughts and excess rainfall are liable to either empty or overwhelm the current systems. It is also recognized that an average temperature rise in the range of 1.5–2.5 °C may be likely to have a significant negative impact on the biodiversity of both flora and fauna, endangering multiple species and potentially damaging the ecosystem's ability to counter the effects of climate change. The location of Singapore is firmly within the region where vector-borne diseases are locally prevalent during the warm season, which may happen concurrently with heat related afflictions in the elderly and infirm. In addition, it is found that urbanization increased the local temperatures due to its ability to produce and store heat in buildings and infrastructures. Consequently, a demand for a higher prevalence of cooling technologies such as air-conditioning units and associated energy burdens is likely, thereby increasing the release of GHGs. At a wider scale, since

Singapore is reliant on global imports for the vast majority (>90%) of its food provision, distant climate change effects on the food production may still have a knock-on effect.

3. Benefits of 5G Technology Applications against Climate Change-Related Risk Factors

The latest version of the digital telecom technology called 5G networks was released to the general public in 2018 and, since then, it has seen global implementation. Although it primarily aimed to provide higher rates of data transmission, the emergent network is rapidly becoming the tool of choice for the inter-communication needed within the greater IoT ecosystem because it offers appropriate cost, delay, and speed. Figure 3 depicts the eight key requirements of 5G network technology [25]. A key feature of 5G technology is the increased level of connectivity between everyday objects, facilitated by faster internet speeds with smart facilities indicative of the forthcoming 5G driven revolution in IoT. This technology offers impressive levels of robust and dispersible connectivity across the entire globe wherein the key design features such as low latency and high transmission rates [26] ensure the possibility of instantaneous processing between multiple locations. In brief, this allows the implementation of new ideas that were not previously possible with its predecessors. At present, the concept of IoT is well known [27], describing the smart devices that are restrained to perform a specific or limited subset of tasks compared to a general device such as a smartphone or computer. Easily recognizable examples of IoT in practice include security cameras, central heating controllers, and white goods.

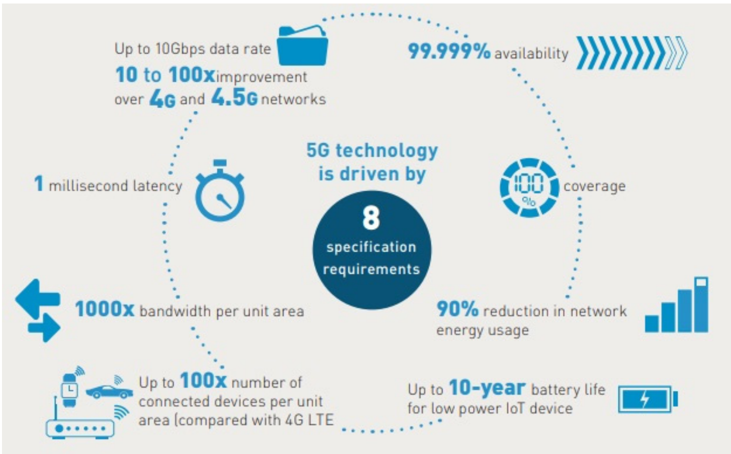

Figure 3. Specification requirements of 5G technology [25].

Today's smart city is an enabling platform that delivers advanced services for its businesses and residents, providing a better quality of life for all [28]. Network infrastructure is critical for realizing this potential. Defined by its high-speed, low-latency data transmission, and ubiquitous connectivity, a well-planned infrastructure transforms the cities into vibrant socio-economic communities. The Internet of things (IoT) is utilized as a part of the smart city through instantly collating data that can be used to rapidly and cheaply adapt the public systems in response to demand fluctuations. The ecosystem of a digital city is one that operates through the interplay of multiple congruent networks, each serving as a distinct element of the conurbation, such as mobile devices, cars, white good, sensors, or communication gateways. Current estimates of IoT take-up suggest that 5G technology will be responsible for 75 billion interconnected devices by the end of 2025. These devices are expected to generate enormous data that can be used by the public sectors to guide their policy developments in a way that offers the best results for participants. This system is generally termed as "Massive IoT" infrastructures. In addition, 5G technology will usher in a new era of smart energy management, smart houses, smart farms, smart buildings, and much more (Figure 4) [29]. Therefore, 5G cellular networks will be more densely connected and will be the main catalyst for IoT innovation and technologies, contributing to more sustainable cities.

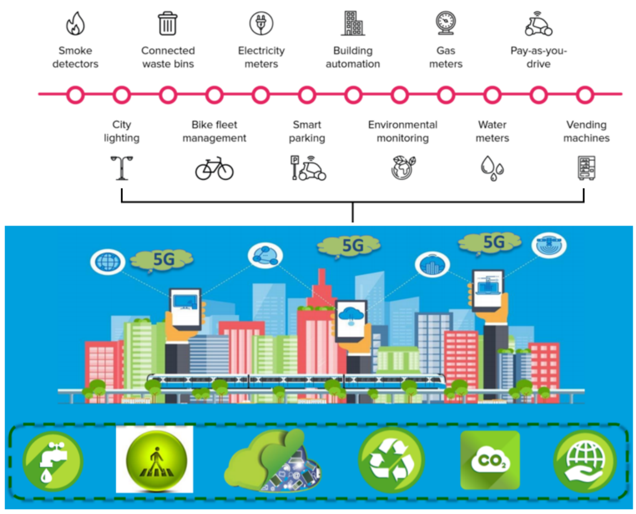

Figure 4. Effect of 5G technology on sustainability of cities and climate change control [29].

The creation of smart cities strongly depends on the increased use of 5G networks, with the cities around the globe racing to improve all aspects of their governed realms through the social, monetary, and environmental gains offered by this technology. Furthermore, 5G network offers the basis for the next generation of technology to be built upon. The reasons why 5G is appropriate for the smart solutions to city management are primarily due to its enormous computing capacity and extent of connectivity. The use of new technology can be highly effective to improve energy, waste, water resource, traffic flow, and parking management. The end result is that a house, farm, factory, building, and city can be more efficient, termed as smart management. Overall, it may greatly reduce carbon dioxide emissions and climate change problems.

3.1. Smart Energy Management

In recent times, the global energy generation, supply, and demand have been affected by multiple factors, including the variation of adverse weather events, sea states, temperature, and rainfall. Many aspects of human life are governed by energy availability. Electricity is necessary for vision and temperature control, while fossil fuels are essential for heat generation, motion, and food preparation. The extent of energy requirements is dependent of the style of contemporary living. In fact, the availability of different services, economic status, types of lands, and local population all have significant effects on energy requirements. The majority of fossil fuel-derived energy is the main contributor to climate change. For example, over 84% of the recorded GHGs released in the United States come from this outlet [30]. The global temperature rise is likely to increase our energy demand and change our ability to produce electricity and deliver it reliably. Worldwide, economic growth and development require energy. The increased concentrations of key GHGs are the direct consequences of human activities. Since anthropogenic GHGs accumulate in the atmosphere, they produce net warming by strengthening the natural greenhouse effect. Specifically, energy production and consumption have various environmental implications, one of which is climate change [31]. Amongst various human activities that produce GHGs, the use of energy represents by far the largest source of the emissions. In essence, GHG emissions related to energy can be cut in two ways [32]. First, by opting for the cleaner energy sources wherein the fossil fuels need to be replaced by non-combustible renewable sources. Second, they can be lowered by reducing the overall consumption of energy via its saving and efficiency gain through smart energy managements.

An ever-increasing number of property developers are investing in Net-Zero Energy (NZE) buildings as a means of reducing their utility costs with the additional benefit that they help to tackle the climate change [33,34]. Although complete take-up has not yet been achieved, both lowering energy requirements and meeting them through sustainable ways offer attractive evidence of cheaper and more responsible business practices. In effect, while NZE constructions work towards the common goal of renewable energy provision, there are personal benefits to the owners in the form of reduced expenditure. The combination of 5G network, design, building techniques, and technologies that go into a zero-energy home (all result in a home) can produce net zero carbon emissions. This implies that such smart homes and buildings are not going to contribute to climate change. Some recent reports revealed that the construction sector is less innovative than other sectors. Historically, building contracts were awarded to those who charged the least, with little regard given to other factors such as material sources. Modern experiences have changed their intent, seeking to ensure that their procurement used the most appropriate and cost-effective options for construction. This strategy became doubly effective as it has also benefitted societal health and local ecosystems [35,36]. The construction sector is one of the key sectors responsible for global warming through excessive carbon dioxide release [37], which alone uses 10% of the global energy and causes 40% of the global refuse [38]. Current fears about eco-stability and energy security mean that buildings seeking to ensure these properties are being readily promoted [39].

A structure that is built without adding to GHG discharges or using more energy than it can produce over its lifetime is described as NZE [40]. They provide power without any dependence on centralized distribution [41]. This method of design can be applied worldwide, even in places subject to adverse weather. Typically, they need higher energy for safe use and become increasingly attractive because the sustainable nature of the generation methods ensures that GHGs are not released into the environment [42]. The development of such structures became possible due to the help of academia that conducted detailed assessments of the data describing the energy demands and industrial growth in the form of innovative technologies. These structures are not yet the norm for the developed nations despite their increasing prevalence. Contemporary software can determine the efficacy of different prototype solutions to a given problem, and thus NZE protocols offer an opportunity to lower both GHG emissions and dependency on the archaic forms of energy supply. It became clear that there are no exceptions to the idea that any process will release carbon dioxide into the atmosphere, not even for construction. The main way of GHG reduction is through the minimization of fossil fuel combustion. However, by simply minimizing its usage one may not be able to remove the daily demand of energy across the global economy. This should make it readily apparent that NZE constructions provide an ideal solution to this constrained demand by allowing the users to generate their own power at the point of use. It is important to note that a true NZE building can offset the carbon dioxide emissions produced throughout its construction by generating renewable power on site [43].

High performance structures such as NZE buildings are the ideal response if the construction industry desires to tackle climate change, since they provide similar benefits to both constructor and user in terms of energy generation and use, as well as associated health and wellbeing. Consequently, the increase in NZE tactics can certainly increase a nation's economy [44]. Global recognition that the earth is a finite resource is a key factor in the transition to NZE construction as a means of ensuring sustainability. The NZE certification for the buildings is awarded by the highly reputed International Living Future Institute (ILFI), with their first award in Southeast Asia having gone to the National University of Singapore's (NUS) School of Design and Environment building. This NZE building is the first fully 5G enabled one in Singapore (see Figure 5). Contemporary design places zero energy status as the pinnacle of the global achievement. To achieve this recognition, a building's ability is assessed and must show proof that it meets the entirety of its annual power needs on site without burning any fossil fuels at all. This is recognized as a unique global assessment. To complement this, the ILFI (which operates on a charitable basis) awards an additional certificate when a building meets the expectations of the demanding Living Building Challenge.

Figure 5. Singapore's first 5G-enabled NZE building in NUS.

Recognition of buildings, such as the NUS-School of Design and Environment building, as zero energy establishments is the key to tackling climate change issues. The nature of the design shows that, by working as a team, humanity can create structures meeting their own demands and thus ensuring global recognition as a means of providing inspiration for future designers worldwide. The building itself has six floors and an effective footprint of 8588 m^2. Although the principle architects were NUS Design and Environment, it was a joint venture conducted together with multiple parties. The key feature of the finished building is the wholesale implementation of the energy efficient provision of climate control in a tropical environment through sustainable means. The most pertinent feature is the use of the 1200 solar panels that constitute the roof of the structure, which alone are sufficient to meet the energy requirements of the residents. The well-powered structure is turned into a pleasant work environment through the integrated 5G-enabled cold air provision. In addition, it negates the higher temperature and moisture content produced by the increasing air flow within the working spaces through a system of fans. The smart nature of the building ensures that it can avoid unnecessary expenditure such as cut-off features implementation in the air conditioning that are activated if the occupants are detected to have opened external ventilation. The building includes innovative ideas that are at relatively low levels of implementation across the world as a means of ensuring The National University of Singapore can meet its NZE targets. Furthermore, it provides the ideal starting point for the rest of the nation to become aware of the benefits of urban sustainability.

A brand new 5G laboratory located in the NUS-School of Design and Environment building has been created specifically for research activities. Incidentally, this laboratory is the NZE building in Singapore. It is essentially a living laboratory in which technology solutions are aimed at promoting sustainable development in a human-oriented manner. Moreover, this environment also enables green building technologies to be test-bedded and developed. In the School of Design and Environment building, 5G networking serves as the primary enabling technology. Thus, the building is an excellent research area devoted to developing and testing the practical Virtual Reality (VR) and Artificial intelligence (AI) solutions designed to improve person–environment wellness through a sustainable ecosystem. StarHub's 5G network powers these 5G concepts at the laboratory, which are broadcast via a 3.5 GHz trial spectrum. The 5G technology provides ultra-reliable low-latency communications and enhanced bandwidth performance. These are the two key features necessary for the VR and AI solutions to run seamlessly. With the emergence of IoT, it became cost-effective to implement a digital twin of a building's operation that continuously learns and updates itself using the information from the building energy management systems. The role of 5G network in this case is to address the need to support multiple IoT devices in a small area. It helps for the data analysis over the cloud to achieve the real-time information from various IoT devices. In addition, the low latency of 5G network ensures a more real-time analysis of the data [29].

A pathway to achieve the net-positive energy is based on the School of Design and Environment building annual post-occupancy studies and energy audits from April 2019 to March 2020. Prior to the COVID-19 circuit breaker period in Singapore, the School of Design and Environment building has performed beyond its net-zero design intent. Beyond the design intent, this building expected a net-positive energy outcome. This resulted from a concerted and collaborative effort by the School's management and building users that ensured a prudent consumption of energy all-year-round. A Building Management System that includes the Occupancy Sensing Thermal Controls and Indoor Environmental Quality Monitoring overseen by the school ensures that these trends in building occupancy and energy usage are monitored and studied for a continued and sustained impact throughout the building lifespan. The School of Design and Environment net-positive energy building achieved several benefits, including the promotion of the health and wellbeing of occupants, saving energy and maintenance costs, and a reduction in GHG emission and climate change, thus creating a more resilient future.

3.2. Smart Wastes Management

Waste management has numerous impacts on climate change and the environment, such as landfills, waste recycling, incineration, and composting [45]. Climate change is expected to produce more frequent and powerful natural disasters that will increase the amount of disaster-related waste generation. Communities can adapt to these disasters and increase their resiliency by preparing beforehand through pre-incident planning. Planning can expedite the removal of waste during and after an incident, which can reduce dangers of fire and personal injury, as well as disease vectors, by identifying waste management opportunities and strategies. Greater levels of GHGs exist in the environment due to human interference which is causing the global surface temperature to rise and initiating climatic changes. Gases such as CO_2, methane, and nitrous oxide are the main constituents of the GHG cohort [46] that are produced during waste management and disposal. Table 1 shows the estimated total emissions of these gases from Europe and the contributions from solid waste disposal [47]. It is worth noting that the uncertainty concerning these emission estimates are significant. The impact of solid waste management on global warming is equivalent to the European GHG emissions that mostly emerge from CH_4 being released as biodegradable wastes decay under the airless (anaerobic) conditions in landfills. About one third of the anthropogenic emissions of CH_4 in Europe is due to this source [48]. In contrast, only 1% of N_2O emission [49] and less than 0.5% of CO_2 emission are associated with solid waste disposal.

Table 1. Anthropogenic emissions of CO_2, CH_4 and N_2O in the EU [47].

Direct GHG	CO_2 Fossil	CH_4	N_2O
Emissions (Mt)	3.215	22	1.05
GWP (over 100 Years)	1	21	310
Global Warming Equivalence of all emissions Mt equiv CO_2 (% from solid waste disposal)	3.215 (<0.5%)	460 (33%)	325 (1%)
Global warming equivalence emissions from waste disposal Mt equiv CO_2 (% of total waste management component for each gas)	15 (9%)	152 (89%)	3 (2%)

Nature exists in a balance and the most difficult challenge faced by mankind is not due to the exploitation of nature, but is to maintain this critical balance while doing so. Massive exploitation of the earth's crust has provided man with endless natural resources that are constantly being transformed into products and discarded as waste after serving their purpose [50]. Unfortunately, man cannot return these waste products to their crude state in the earth's crust. Hence, the easiest route of escape is to release these materials to the atmosphere in gaseous forms. The accumulation of these gases in the atmosphere over many years has upset a critical balance of nature. The issue of global warming and climate change will continue to be a threat until humans learn to return used or waste products in their crude forms to nature. Obviously, this is impossible and the closest that humans can ever achieved to this is the recycling and reusing of waste. The most popular contributor to global warming via gaseous emission into the atmosphere is the burning of fossil fuel. Recently, dedicated efforts are being made, especially in developed nations, to reduce dependence on fossil fuels as a means to reduce global warming. However, a silent but massive contributor to GHG emissions is waste management. A recent report by the United States Environmental Protection Agency estimates that about 42% of the total GHG emissions in the nation are associated with waste materials management and disposal [51]. A simple analysis reveals that the activities associated with waste disposal and management can contribute a total of 57% of CH_4 emission compared to 26% contributed by energy production.

Waste management options such as landfill, composting, incineration/mass burns, and anaerobic digestion/biogas plants collectively emit a substantial amount of GHGs. Composting makes use of micro-organisms to oxidize the biodegradable wastes (especially food and garden waste) to CO_2 and water vapor using oxygen in the air as the oxidizing agent. Anaerobic decomposition converts biodegradable carbon to biogas that consists of about 65% of CH_4 and 34% of CO_2 with traces of other gases [52]. In landfills, the microbes gradually decompose the organic matter over time, producing roughly 50% of CH_4 and 50% of CO_2 as well as trace amounts of other gaseous compounds [52]. Methane emission from landfills represents the largest source of GHG in the waste sector, contributing around 700 million tons (Mt) of CO_2-e in 2009, followed by incineration, estimated to contribute around 40 Mt of CO_2-e [53].

Lately, smart cities are providing dynamic control of their waste streams [54]. Companies are now better equipped with appropriate software that enables monitoring the excretions. This has dual benefits such as the reduction of costs and the perceived load on the local ecosystems. Both individuals and businesses refuse management has received multiple high-tech updates such as self-sorting and collection tools. OnePlus systems are the recognized toolbox for smart waste monitoring. An example of this is the OnePlus Metro, which is a sensor capable of providing real-time analysis of the free capacity currently available within on-site storage bins. Combining this with the WasteForce platform provides facile opportunities to monitor this capacity remotely. In addition, it performs in-depth data assessment and evaluation as a means of dynamic business management. The end result is that the business is less likely to face financial penalties through the failure of waste disposal in a timely manner. At a wider scale, the data can be collated by refuse collectors as a means of ensuring the efficiency of their service can be maximized or through installation of remote image sensors in their refuse storage bins that allow for personally monitoring the charges in real time. As an additional benefit, the inclusion of location tracker sensors using Global Positioning System (GPS) technology offers the chance to streamline the delivery and collection process on the fly. Further data are provided by in-line tilt monitors that offer a proxy for marking off when a bin has been emptied. These features of the smart system work together to ensure that drivers on the ground can better manage their agenda, minimize the time of travel and distances, and adjust the schedules in response to sudden changes immediately after receiving the automated text instruction. It is clear that the implementation of such systems can go beyond immediate reduction of waste generation and increased recycling, indicating the existence of knock-on effects such as tackling climate change.

The term IoT is used to describe a network of embedded devices that are interlinked via the internet and can be remotely managed. Connecting trash cans to the internet via smart waste management software provides the operators with live data on their service demands. Contemporary increases in population growth have resulted in a related increase in refuse disposal. Without appropriate action being taken, there is an increased likelihood that disease transmission between populations will occur more readily. Smart refuse storage can be remotely tracked and the data can be used to guide the outcomes. These storage bins are typically dispersed throughout a given jurisdiction across multiple scales (business, school, neighborhood, and city). They contain built-in computational control managed by the infrared and radiofrequency parts. The infrared signal is used to measure the height of wastes currently in the storage bin. Then, the result is encoded and transmitted using radio broadcasting to a central hub where data from all sites can be collated. The hub can then provide summaries via the internet to the system operator, enabling them to perform a variety of processes via a graphical user interface within a simple web browser [55,56].

In Singapore, both hazardous and safe solid wastes are managed via the plans derived by the National Environment Agency (NEA). This agency has legislative control over the regulations governing waste treatment and disposal. These regulations include the Environmental Public Health Act, Environmental Public Health (General Waste Collection) Regulations, Environmental Public Health (General Waste Disposal Facilities) Regulations), and Environmental Public Health (Toxic Industrial Waste) Regulations. In the 1970s, Singapore used to excrete approximately 1260 t of waste daily. The combined economic and population growth it has experienced since that era led to an increase in the waste levels seven times higher at present [57], a figure which is expected to continue to rise as long as these growths continue. This has, in turn, come into conflict with the nation as a whole, since waster must have sufficient room for storage, and the state is severely restricted in the availability of land stock suitable for this purpose. The Singaporean response to this problem is clearly depicted in Figure 6, illustrating different approaches that can be taken towards continual refuse oversight. All of these approaches are reliant on the interplay of different parties from both the public and private realms. The NEA partnership has produced multiple guidance schemes aimed at tackling increases in waste production. For example, the separation of recycling is now undertaken pre-collection, at the source of waste production, as a way to reduce system strain. Non-recyclable waste is later collated and disposed of in waste-to-energy incineration devices, which are capable of reducing the volume of waste requiring further treatment to just that of the non-combustible element, which is approximately 10% of the starting product. The combustible portion generates sufficient heat to turn a steam turbine and contribute 3% of the nation's power demand. The ash and other non-flammable wastes are ultimately exported via Tuas Marine Transfer Station (TMTS) on boats bound for the Semakau landfill.

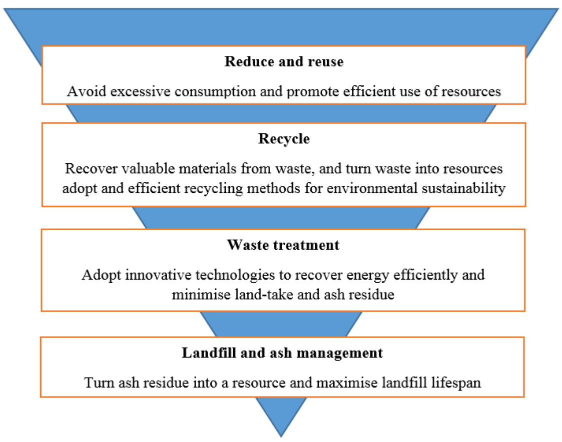

Figure 6. Wastes management strategies adopted in Singapore.

Currently, the greatest energy recovery scheme operating worldwide is in Singapore—the Integrated Waste Management Facility (IWMF) that includes many novel design features which are all cutting edge technology. The collocation employed—it is sited adjacent to Tuas Water Reclamation Plant (WRP)—allowed the facilities to jointly increase their efficiency and reduce GHG emissions. It is clear that there are serious problems to overcome when 5.5 million inhabitants choose to live in such close confines, not the least of which is the provision of potable drinking water and sanitary extraction of waste. In the case of Singapore, this is clearly well tackled by combining solid and liquid waste treatment to increase efficiency across multiple levels. The design of the IWMF-WRP collaboration has been enacted by the National Water and Environment Agencies appointment of an international consultancy to provide facility oversight. This scheme can handle both energy generation from burning solid refuse, and sludge, along with the processing of recyclable wastes in the Material Recovery Facility (MRF).

The building of both sites is a stepping stone in Phase 2 of the extensive Deep Tunnel Sewerage System (DTSS) scheme. It can be considered as a superior method for collation and processing of waste water streams, whereas the IWMF performs a similar task for solid waste disposal. This project will be the first to intentionally design a site around twinned waste management streams. There are clear benefits to improving the water sustainability in operating a parallel solid refuse system around the collection, treatment, and emission of waste water, such as the opportunity to recycle fluids. At a solid refuse capacity of 2.5 Mt, incinerating waste in the IWMF's facility offers five times the output of major European competitors, and the dual stream fluid bed combustors used are similarly world leading. Anaerobic digestion is used to undertake the initial breakdown of biological matter such as food and other organics without the need for supplementary oxygen, which in turn allows Tuas WRP to create biogas.

As a way of updating the 1992 Singapore Green Plan (SGP), in 2002 the Ministry of the Environment and Water Resources published the Singapore Green Plan 2012. In this document, there are eight fundamental aims, whereby the state intends to ensure that Singapore is eco-friendly, and that it uses sufficient green interventions to preserve resource integrity and both local and global environs. A further measure is included which aims to ensure new changes in the land, considering the future, by instilling environmental awareness in the national psyche. The SGP 2012 is re-assessed on a thrice-yearly basis by seeking the views of focus groups discussing elements such as Air and Climate Change, Water and Clean Land, and Nature and Public Health.

IoT, supported by 5G technology, allows the objects to be sensed or controlled remotely across existing network infrastructure [58,59]. This remote sensing and controlling leads to more direct integration of the physical world into computer-based systems, resulting in improved efficiency, accuracy, and economic benefits thanks to reduced human intervention [60]. On a wide scale, when IoT is augmented with the sensors and actuators, the technology becomes an instance of the more general class of cyber-physical systems. It also encompasses the technologies such as smart grids, smart homes, intelligent transportation, and smart cities [61]. It is in the perspective of building smart cities that IoT can be used for waste management purposes. IoT works through an IP address allocated to each object. In other words, each thing is uniquely identifiable through its embedded computing system but is able to interoperate within the existing Internet infrastructure [62].

The current mechanisms for the collection of waste foodstuffs involve multiple unconnected enterprises working along a fixed route in the small hours. Clearly, there are opportunities whereby inefficiency may arise through the excess collection or careless route planning because they run along the same line and are unaware of the volume of waste to be picked up. The system presented herein recommends that the ideal solution to this lack of efficiency in the processing of culinary refuse is due to the implementation of a Smart Garbage System (SGS) which uses Smart Garbage Bins (SGB) as a means of monitoring live capacity. The system envisioned allows pickup drivers to use a smartphone to retrieve garbage levels from each SGB in their jurisdiction, along with their respective locations that have been ascertained by middleware queries, and thus determine which of the SGBs need to be emptied and the optimal route between them that allows for adequate levels of service provision without reducing system efficiency.

Classification of refuse can be assisted by IoT in which manual separation of trash is incredibly labor intensive. New models of digital bins can undertake this sorting on their own. A pertinent case study is perhaps Bin-e, from Poland, a product which features multiple efficiency improving measures, such as AI-trained object recognition, capacity monitoring, and internal data analysis. These trash cans are considered smart, and can distinguish four waste classes—metals, plastics, paper, and glass. A further feature of these bins is their ability to undergo waste compression in conjunction with fill level monitoring which is transmitted to remote operators. Each device embedded in this system provides real time fill speeds daily, while the control system undertakes longer term monitoring by considering the collection rates required. The key strength of IoT networks is their ability to feed into wider reaching aspects of smart city design. The power offered by the size of the data set provided allows for greater-depth statistical analysis for the purpose of maximizing efficacy. There are infinite ways to enact this change, including SGB relocation, addressing public misconceptions about non-categorized items, or lowering the volume of trash which must ultimately be buried. Using IoT as the means of advanced city management for the health of both the citizens and the planet is becoming increasingly commonplace.

Today, the IoT devices are mostly connected via cabled technologies including both shielded twisted-pair LAN and coaxial cables. In some limited areas, Wi-Fi may have some usage, however, it is not always ideal. Further, 5G enables many more sensors to be put in place without a need for cables and a conduit for each cable. In recent years, the development of IoT processes has accelerated with many seemingly futuristic concepts beginning to be considered as the commonplace in our daily lives. Bandwidth is the key bottleneck that must be addressed. Mobile communications are affected by this, despite the distance they may cover. Wi-Fi suffers from the inverse problem, whereby volume is higher, but range is low, in addition to the security concern. 5G has been touted as a solution to these problems, since it can massively enhance the mobile bandwidth, and thus IoT networks become increasingly feasible. Although 5G is the incoming new standard, the current norm of 4G does at least offer upload and download speeds of 7 to 17 and 12 to 36 Mbps, respectively. The rate of transmission offered by 5G (15–20 Gbps) is several orders of magnitude higher compared to the one offered by 4G cellular network, while similarly offering latencies one tenth of 4G. These advances combine to produce a network capable of connecting many more devices together. Due to these reasons, the IoT is built on 5G technology, though the suitability of this remains contentious in academic and professional circles. The key argument presented most often being that the current devices do not require these extreme transmission rates, or minimal latency for their intended functionality, such as asset tracking or remote monitoring, to be achieved. Notwithstanding this, Gartner estimates that two out of three businesses have by now introduced 5G technology, and that alone should provide momentum to 5G take-up.

Implementation of IoT-linked sensor networks offers all interested parties multiple benefits, such as lower pickup charges. SGBs provide continuous fill level monitoring data to the operators. In fact, IoT can be deployed to analyze this data, ensuring that the Lorries take the shortest paths in the service provision. Consequently, only those SGBs which require immediate attention are emptied, and thus both fuel expenses and person-hours are reduced. Collections are guaranteed through the IoT-linked sensor networks operation. Smart processes ensure that fill capacity of SGB is never exceeded, since the relevant powers are always aware of the remaining space in each of their collection sites, allowing them to empty them in good time. That refuse production evaluation can be performed by choosing the ideal path is not the only reason to implement smart tech in waste disposal, instead it is clear that most of the value lies in interpreting the information gleaned. As such, it is rare to encounter an IoT product that cannot offer analysis, which offers a convenient way to find and predict future trends in production. It lowers the carbon dioxide release.

Extensive debate has taken place over the scale and impact of the carbon dioxide released from processing waste and recycling. It is clear that greater path efficiency reduces fuel requirements, and thus the emissions which are the clear way to ensure more sustainable methods are used.

Operators of refuse collection services in urban areas can enjoy considerable advantages from the implementation of the IoT techniques. Examples of these advantages include lower expenditure, more efficient working, and happier consumers, purely by ensuring timely collection and disposal of their refuse. As the number of Wi-Fi enabled technologies available to purchase increases, their associated costs continue to reduce and thus allow for ever more implementation of IoT technology in tackling waste management. Thus, a more cost-effective method is to invest now if the aim is to tackle climate change, as the interplay of 5G and IoT will have a transformative effect in the near future, making urban areas capable of tackling environmental damage. Enterprises will be better able to contribute to this fight by lowering their GHG releases through smart, IoT managed systems.

3.3. Water Resources Management

The effects of climate change on drinking water supplies are often debated at both professional and academic meetings. Rises in the global temperatures are known to adjust the precipitation ratio in the direction of rain, rather than snow. The principal changes would be that runoff would occur in different temporal and spatial regions, with reduced snowmelt in spring due to more water draining earlier in the winter season. This change would be particularly stark in areas of high elevation, and those far from the equator. The end result is that the precipitation may experience local variation in extent, rather than a uniform increase or decrease. These patterns may be mirrored on larger scales, such as with the seasons, or in freak weather patterns. Knowledge of the local weather conditions is used extensively in managing water supplies. The efficacy of the decision made using this information depends on the nature of collaborative analysis undertaken by hydrologists and climatologists. Post-development, the management of water processing and delivery sites is based on past, present, and future climate data [63,64].

Climate being a key design parameter in the systems development and implementation, any changes require adjustments to the tools applied in many areas, in order to ensure the maintenance of demand and supply relation. In this way, both objectives and limitations are adhered to within the remit of managing state water resources. The extent to which these differences have an effect is proportional to the level of climate change through the product lifespan, and the robustness of the system in terms of its ability to mediate the effects of external change—in other words, there is a limit to change, beyond which the assumptions on which a system is built no longer apply, and thus the system becomes unfit for its purpose. Some recent studies demonstrated that climate change has a direct effect on the ability of populations to access potable water reserves [65,66], with areas typically inundated with ample volumes of freshwater now needing to consider how best to manage their resources in a way that allows for occasional shortfalls. For example, the Puducherry area has historically possessed abundant natural reservoirs of potable water; however, the increased need for access to this resource by a growing population and economy, buoyed up by increased agricultural and industrial activity, has begun to affect this availability, with both quantity and quality at risk. Key variations in the local infrastructure, such as land use, crop choices, seawater intrusion, polluting behaviors, and water pricing structures mean that the hydrological cycle in the area is changing quickly. In addition, there are reported differences in mean temperature and humidity, and littoral attrition. Taking all these factors together, it becomes evident that sustainable water supply management and implementation is a critical concern. To ensure this, it is recommended that an objective assessment of the current and future requirements must be undertaken with special concern given to the invariability of a system to changes in atmospheric conditions. As a way to address this challenge, this presentation offers an all-inclusive overview of how best to manage water resources within the limitations imposed by acknowledging and tackling climate change.

Contemporary strategies such as smart management systems ensure that the control of the water supply chain is both optimized and also transparent throughout its entire service from the acquisition to the storage, supply, collection, processing, and eventual re-use. The use of digital systems offers better opportunities to collate and analyze the data used to guide the dynamic control measures that aim to raise the efficacy of the service provided. The end result is a system that is tougher and more immune to volatility in all aspects of operation, implying that expenditure is reduced and the system becomes more of a long term solution. Several modern technologies can be implemented in this regard, such as supervisory control and data acquisition (SCADA) or geographic information systems (GIS), alongside the more conventional sensory equipment. Accordingly, the water resource becomes a composite system that can be described as instrumented, interconnected, and intelligent. In effect, its functions can be monitored automatically, inform higher level overseers of current conditions, and yet undertake independent analysis of the data collected as a means of ensuring low level stability without needing to escalate all concerns.

According to the United Nations, in the year 2025, one fifth of the global inhabitants will be directly affected by water shortages, with the remainder of the population along with the wider environment also suffering from less direct effects. Implementation of the smart systems is a key method through which some of the problems caused by past carelessness can be reversed, thus protecting this shared resource. The AI technology, big data methods, and the IoT are expected to play vital roles in such a reversal [67,68]. The water resource management sector can only achieve its aims using the IoT. A novel concept which combines these elements is described as the Internet of Water. The concept encompasses all relevant parties concerned with the collection, storage, distribution, use, and disposal of water within a given society, allowing them to ensure that decisions made are of equal benefit to all. IoT is the most suitable method to make this connection for the water industry because it has six outstanding elements. The first element ensures that the governing processes are readily visible. The second one involves the live monitoring that ensures problems do not go undetected. The third component deals with the use of automation that allows human resources to be better invested. The fourth element promotes sustainability, reducing the waste streams. The fifth one uses various algorithms to analyze the data and allows different pro-active strategies to be implemented. Finally, the sixth element allows the water industry to mediate its climate change contributions.

The water sector is increasingly more aware of the fact that natural resources are limited and we are using them at their maximum or close to their maximum potential. It is essential that we identify not just current needs, but also future needs, in order to ensure the sustainability of water resources. With artificial intelligence, not only is it possible to automate risk management, but also to simulate the behavior of water networks under different scenarios and detect anomalies, thus improving efficiency. Because of its large magnitude, the water sector needs information and knowledge exchange that is transparent, fast, flexible, and secure, among all actors involved in the integrated water cycle. The block-chain enables closing the water services' purchase–sale transactions digitally between the actors themselves, at the same time as transparency and secure non-personal data flow are strengthened [69]. The water sector is already immersed in an unprecedented technological change. The new technologies are having an impact on the way entities function, transforming business as usual, and creating and changing the opinion trends of end users. In fact, the entities dedicate more and more resources to prevent any potential risks and use the opportunities that Industry 4.0 offers for integrated water cycle management.

The development of the IoT has meant that enterprises can now seek to install sensors throughout their operations as a means of collecting and passing data to both internal and external collators. It is predicted that such a strategy can only increase efficiency across the business as a whole. The use of 5G-IoT smart solutions to business quandaries will enable them to reduce their carbon footprint. This 5G-based Smart Water-control and Monitoring tool ensures that real time, fine detail analysis, and dynamic control can be applied to renovate the antiquated approaches of water management. The global implementation of 5G ensures that this fight can be picked up around the world, so that a planetary approach can be taken to ensuring access to safe water sources in the future. It is anticipated that the reduced delays in reportage offered by 5G's inherent construction will mean that more timely responses can be made in response to emergent issues. Due to the interconnected nature of these new systems, the response will be better informed, as all relevant parties will have equal access to the data storage. Of note is the scale of the increase in device handling capability from 4G to 5G. While the former is limited to ~60,000/km^2, the latter can accommodate over a million unique devices. In brief, there are clear and tangible benefits to using 5G rather than 4G in the water industry, as the latter will never be capable of providing sufficient bandwidth so as to be able to conduct remote live monitoring in HD quality of both water and waste plants.

3.4. Agriculture Management

The amount of water that plants require for growth depends on overall soil humidity. This is typically measured by manually applying sensors on site; however, this task could be readily undertaken through smart sensors, which would provide a more efficient, timely, and accurate means of monitoring. The IoT in an agriculture framework includes various benefits in managing and monitoring crops [70]. Developing an intelligent system using IoT for agriculture could be able to monitor the crops growth and its environment [71,72]; even though the collection of raw data is important [73], the mining and analysis of the data is also considered to be an essential task. Agriculture field products [74–76] have several issues which can be solved with IoT, enabling one to predict, monitor, and manage the cycle of agriculture products. In several countries agriculture is the largest livelihood provider; with nearly half of the population still relying on agriculture for income [77].

Zhao et al. [78] proposed the integration of IoT technology to real-time production of agriculture crops with remote monitoring and wireless communication using the internet. This constitutes a management system of information which is also designed to handle the crop data for research purposes. Ning and Wang [79] differentiated IoT in two aspects, namely Unit IoT and Ubiquitous IoT, where man's like neural model (MLN) is considered in unit IoT and a global integration of unit IoT is considered as ubiquitous IoT. Using this combination, a social organization framework model (SOF) was constructed for the relationship and development of IoT. Yane [80] discussed various methods to design the IoT architecture for agriculture wherein the Agriculture information technology (AIT) concept was used to analyze the features of agriculture data. Ma et al. [81] reported the use of sensor networks design on IoT in agriculture for monitoring the crops, and the design is evaluated using parameters such as reliability, cost, interoperability, and management to ensure the right design. Hu et al. [71] proposed the concept of embedding the IoT applications with crops growth, which makes the system adaptive and intelligent by experimenting on different fields. All these abovementioned studies emphasized the challenges faced in developing an intelligent system.

According to International Business Machines Corporation (IBM), IoT implementation should increase agricultural yields by 70% within the coming thirty years. In fact, IoT is well equipped to tackle problems encountered by today's growers. There are a large number of smart technologies within the Agritech sector that are designed to satisfy farmers. On-site monitoring of watering, planting, crop intake, and pest levels allows for more effective site control. The most common use for IoT in agriculture is in considering weather patterns. The unsettled nature of climatic conditions mean that expected crop yields change regularly. Changes in the elements, such as humidity, temperature, rainfall, sunlight, and wind, can be monitored from sites in specific fields. The delicate nature of cultivating under glass means that constant monitoring is needed. Therefore, many opportunities are there to introduce smart technologies for assisting this from afar, as they are readily able to monitor variables such as light, humidity, temperature, and atmospheric compositions, as well as adjust them to keep within a desired range. The ability to transmit real time warnings when levels are exceeded ensures operational efficiency. Both indoor and outdoor farming spaces are suitable for smart sensor installations, and can lead to a stronger, more unified approach to agricultural management. It is anticipated that any such system should aim to interface freely with other smart elements aimed at account and procurement management, so that whole system efficiency may be maximized. The data collected from sensors monitoring soil moisture, humidity, and crop condition can be analyzed using a variety of pre-planned or adaptive techniques in a smart system, which allows for the irrigation of said crops to be dynamically managed.

Using the environmental sensors and predefined or self-learning algorithms, a smart distribution system provides automatic water supply to the endpoint. For instance, in smart irrigation, the sprinkles provide just enough water depending on the reads from soil moisture, air humidity, and crop condition sensors. The Industrial IoT has been a driving force behind increased agricultural production at a lower cost. In the next several years, the use of smart solutions powered by IoT will increase in agriculture operations. Actually, a few of the recent reports tell us that IoT device installation will see a compound annual growth rate of 20% in the agriculture industry. Further, the number of connected devices (agricultural) will grow from 13 million in 2014 to 225 million by 2024. Clearly, the introduction of 5G technologies is likely to radically alter the way that cutting edge industries, such as the automotive and high-tech sectors, operate. However, it has less obvious, but similarly wide scale application within agriculture, an area which has historically been resistant to change. Tasks such as pest, fertilizer, and water level monitoring, field condition analysis, livestock tracking, and the control of drone operated machinery are ideally suited to 5G connectivity. Although many sectors receive benefits from 5G implementation, in the world's overall economic growth, the agricultural sector must be initially focused as it will readily assist by allowing for more data to be collected that can be used in the dynamic management of agricultural sites such as farms.

3.5. Risk Management

There are four recognized strategies to manage the effects of climate change. The first one aims to lower the levels of GHG released. The second one aims to weatherproof our current way of living. The main goal of the third strategy is to determine intentional anthropogenic change as a means of directly countering the unintentional ones. The fourth and final strategy aims to better understand the climate itself, and thus offer more forward-thinking approaches to minimizing humanity's effects [82,83]. Lowering the extent of GHG release ensures that the fraction of the earth's atmosphere that they comprise should be reduced in the future. This in turn means that climate change should decrease, and increases the likelihood that society remains able to mitigate the worst of its effects. Multiple emission reduction strategies can be employed to reduce GHG releases, such as regulation, innovative technology application, conservation, public education, or either financial incentives or penalties for greater or lower emissions [84].

In the view of the climatologists, there are two competing futures depending on whether society acts to tackle climate change. The first assumes failure, and results in higher temperatures and many new threats, while the other requires that global mean temperatures do not exceed the two-degree threshold (above pre-industrial measures), which must be met through combative strategies, by 2100 at the latest. Thus, the risks associated with climate change are either physical, whereby responses seek to tackle their negatives, and preventative measures associated with transitional arrangements seeking to move society to a cleaner, green future. Although there is a clear need for collaborative action in terms of society's response to the broader problems identified, individual enterprises can all play their part at a smaller scale. To this end, the design and implementation of a climate resilience adaptation strategy is recommended by Zurich.

They further elaborate on this ideal, suggesting that concerns should be identified and mitigated at both macro and micro scales if a business is to be secure. Larger enterprises should seek to address their greenhouse gas emissions as part of their overall business strategies moving forward; this is particularly pertinent to those with high levels of carbon dioxide excretion, which may be well assisted or retarded by the outlook of their governing boards.

Businesses have an extensive risk management toolbox available to them. A common method for managing risk is to utilize Zurich's Total Risk Profiling (TRP) as a means of identifying, quantifying, and mitigating threats based on ideal response protocols. An example of this may be found by considering the suitability of the Post Event Review Capability (PERC) as a means of reviewing instances of flooding. This is carried out by determining all aspects of resilience, control, and mitigation, seeking to ensure that current best practice protocols remain up to date, and identifying those which need to be further improved. Through this tool, Zurich is capable of providing consultancy services to those seeking to address a range of climate related concerns. Two of the most desirable innovations from the perspective of tackling anthropogenic climate change are the carbon capture and electricity storage technologies, since both have clear and immediate benefits to the global threat. Research is continuing apace in both regards, since the longer it takes for a solution to be implemented, the greater the problems associated with the collective failure to act will be, more time will be required to rectify them, and thus exists ever greater threats of adverse weather damage.

For risk managers, the IoT revolution is often about grappling with new risk exposures and potential changes to liability, rather than enjoying the exciting potential of these new technologies. However, that is no longer so because IoT is now producing very real benefits for the risk profession. The IoT devices envision a future where interoperable, reliable, secure, and efficient digital devices communicate and are linked by appropriate communication technologies. These digital devices help in generating big volumes of sensitive data with a high processing speed. Such information is helpful in empowering users but imposes a great cost of data loss or data misuse. As data complexity, technology and pervasiveness grow, so does the argument to perform risk management [85]. The efficiency of IoT with 5G technology will be better and highly effective on risk management, on the positive side.

3.6. Economic Management

As well as the potential damage to the earth and its inhabitants, the economy on which they depend is also threatened by climate change. To combat this threat, the response must be devised between both public and private enterprises as a means of ensuring that future economic growth is sustainable [86]. High temperatures negatively affect the human condition and make it harder to work efficiently, while a tropical storm's capacity to destroy millions of livelihoods in an instant can decimate local economies and communities. The occurrence of acute water shortages damage crop yields, meaning that less food is available to feed an ever expanding population that is rapidly approaching ten billion people (World Population Prospects 2019, United Nations Organization) [87]. A stark comment from the World Bank acknowledges the risk that in the coming decade, a further 100 million people could be classed as impoverished because of the effects of climate change.

Despite acknowledgement and implementation for the remedial measures, climate change has been slow in the capitalist society wherein more and more enterprises are showing their eagerness to do their part to tackle this global crisis. This in itself offers the perfect chance to change our collective outlook to ensure sustainable processes are embedded into global culture. This is further incentivized by a World Commission report on the Economy and Climate (2018), which estimates that wholesale tackling of climate change could generate over 65 million employment opportunities in the low carbon sector, which is accompanied by a potential profit margin of USD$26 billion in the coming decade. Various strategies have been adopted to reduce the GHG emissions from the development.

The adaptation strategies make the communities more resilient to the effects of a changing climate. Smart growth strategies also bring environmental benefits and provide economic advantages to local governments and the private sector. In addition, they can save people money on energy and transportation, which is particularly important for low-income residents, and helps to protect human health. In recent years, the evaluation of climate change's effects became more important because the effects are becoming more noticeable. National level risk assessment ensures that governors are adequately prepared to develop a response, since they have already quantified their available physical and human resources, ensuring their focus on policy development. Singapore's status as a financial city state and clear personal need for global climate change mitigation means that it is well incentivized to offer insurance policies to its near neighbors. As such, over two hundred firms are competing to provide insurance coverage to the Asian market.

Several Singaporean institutes have focused on climate change, such as the Institute for Catastrophe Risk Management (ICRM) at Nanyang Technological University. This is a young enterprise, having only a decade of operation, but is the first Asian team to focus on this field. As well as its titular aim, it seeks to form joint ventures with other relevant teams in China/Japan. Insurance brokers benefit from their research, since it allows for accurate assessment of the financial risk and gains to be made that result from climate change. The Earth Observatory of Singapore, like ICRM, seeks to identify the local effects of this global problem, with a particular focus on those caused by the Indian Ocean Dipole and the Western Pacific Warm Pool. The Centre for Hazards Research (CHR) at NUS has a highly localized approach and clearly targets Singapore's infrastructure and the ways in which it can advance as a means of mitigating the threats posed by natural disaster. The emergent 5G network technologies have appreciably lower latency, higher capacity, and higher bandwidth compared to 4G technologies. Certainly, 5G technologies have far-reaching impacts on the living and working standard of Singaporeans. Figure 7 elucidates the benefits of the application of 5G network technologies in various sectors, controlling the adverse effects of climate change on human.

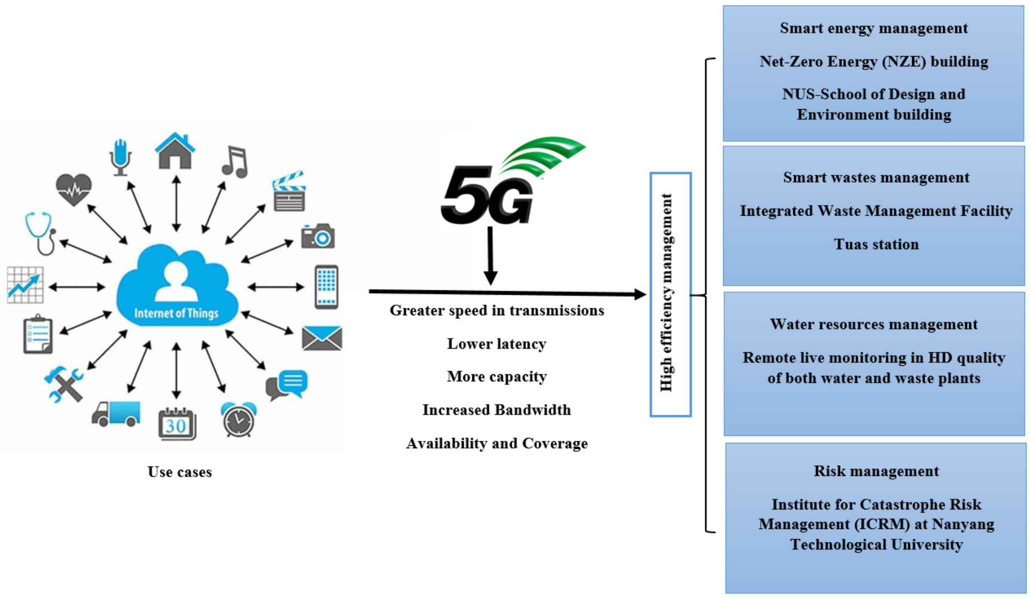

Figure 7. Benefits of 5G technology applications in Singapore.

4. 5G Smart Cities

5G network, as the latest wireless communication technology featuring ultra-high speed, super low latency, and massive connectivity, is bound to have a profound impact on smart cities. With a 5G-based ubiquitous sensor network, the Internet of Everything can become a reality in smart cities, where people, machines, and things are highly integrated [88,89]. Diffusion and availability of new technologies are required to transform a city into a smart city, contributing to reaching a high level of urban sustainable development and improved quality of life for its citizens.

Smart cities technologies, smart grids, and smarter energy use have become prominent themes in recent years. There is little doubt that these technologies are spreading and growing in influence [90]. As well as playing a crucial role in improving cities and their infrastructures, smart buildings can also significantly enhance the comfort of residents. This is because they improve energy efficiency, available services, quality of life, safety controls, and general comfort. Many different definitions for 'smart building' have been put forward, most of which are based on energy efficiency and the concept of a "smart grid". Intelligent management systems contain features that enable mass data to be stored and analysed. Thus, when implemented in buildings, they can significantly enhance energy management. This is because electrical devices on a grid can learn and adapt to new behaviours, which is essentially what makes them 'intelligent' building systems. Therefore, services that incorporate IoT and Big Data technologies are intelligent because they employ vast amounts of data in analytics and automatic learning [91]. 2019 is the first year of 5G commercialization. Seeing the urgent need for the planning and development of 5G smart cities across the country, 5G-led ubiquitous sensor networks have become a cornerstone of smart city development; meanwhile, the unique ability of 5G networks to meet differentiated smart city needs, smart edge systems have been built on 5G and other technologies for collaborative intelligence. The below table (Table 2) summarizes several applications of developed technology for smart homes, buildings, cities, industries, and infrastructure.

Table 2. 5G application cases in smart cities.

Ref.	Country	Building Type	Major Use Case	Related Building System
[92]	Italy	Business building	IoT	Building maintenance applications for end users
[93]	China	Hospital	IoT	Occupant localization for hospital department route direction
[94]	Singapore	Residential building	IoT	Smart grid (energy control) system for residential building.
[95]	Malaysia	Hospital	AI	Using AI for drug discovery applications.
[96]	USA	Hospital	Machine learning	HealthGuard platform to continuously monitors and compare the connected devices operations and body conditions.
[97]	South Korea	Smart factory	AI	Improve the efficiency of horizontal data distribution and exchange operations, reduce the time and cost, the problem of data loss, system performance degradation, real-time processing delays, and the ability to accommodate a number of machines and a number of single protocol products.
[98]	Sweden	Smart industry	AI	predictive maintenance, big data management.
[99]	Finland	Smart factory	AI	The model allows for distribution of network functions between business actors over multiple network domains.
[100]	USA	Smart transportation	IoT	To improve traffic congestion, a smart transport system that dynamically tracks, monitors, and publishes city-wide traffic in real time has been developed.

5. Challenges, Recommendations and Future Works

This comprehensive literature survey revealed the promises of 5G network technology applications in smart cities. However, the following challenges need to be overcome through a set of recommendations for which further works are essential:

i The concept of the smart city will continue to evolve. Yet, only the developed countries are engaged in such experimentation and implementation. Singapore is one of the leading nations taking initiatives to employ citywide sensor data to monitor daily life. Singapore's Smart Nation program encompasses current technology infrastructure to create an online connection for all the involved communities. Smart cities have wide-ranging benefits that can be applied to any urban area. Hence, future studies on cost-effective design and implementation are essential to increase the focus on the smart city concept globally. It is also vital to include renewable energy sources so as to safeguard the viability of city operations, addressing the various issues related to the non-renewable energy sources;

ii Future smart cities should comprehensively examine the big data analytics of the existing smart cities;

iii In the connected environments, it is critical to safeguard the security of sensitive data, because in the case of any doubt, the citizens may not utilize the ICT platforms, thereby decreasing the city operations' viability and reliability. Hence, a key area for future research may be the implementation of collective security measures in smart cities;

iv The other area that requires an in-depth investigation is the optimization of the advantages of diverse devices. Further analyses are required because smart cities integrate a range of subsystems at the application layer in order to provide reliable and efficient services. Due to its universal accessibility, the web inspired WoT concept is considered as an ideal element to combine diverse applications. Consequently, smart city constituents can effectively intercommunicate regardless of any conflicting components in the communication technologies or operational platforms.

6. Conclusions

Climate change is the most significant challenge towards achieving sustainable development because it threatens to drag millions of people into grinding poverty. Lately, several countries have taken bold steps to confront an emerging urban crisis with multiple dimensions including the damage to the quality of life caused by GHG emissions and threats of climate change. There is an urgency to develop policies that support green and smart city innovation. An all-inclusive overview of the relevant literature on the upcoming 5G network technology application in Singapore allowed us to draw the following conclusions:

i The necessity of a high bandwidth, low latency, and customized network for supporting various network-related requirements including smart facilities management that cannot be fulfilled with the current networks was demonstrated;

ii The 5G technologies-enabled smart cities concept has been prioritized in Singapore to maintain public comfort within the buildings, energy efficiency, environmentally friendliness, and intelligence. It is expected that the intelligent buildings in the near future will become more significant in the context of large buildings;

iii Low rise institutional buildings and schools have the potential to achieve zero or positive energy targets first;

iv The smart management of energy, wastes, water resources, agricultures, risk factors, and economy adopted in smart cities can remarkably contribute to reducing climate change, thus attaining the sustainability goals.

v The smartest management depends on the applications of the developed technologies such as IoTs, artificial intelligence, and so forth. In fact, 5G network technology can provide ultra-high transfer speeds, ultra-low latency, ultra-reliable experiences, ultra-high connection density, ultra-high traffic density, and ultra-high mobility access to the users. In addition, it can offer enhanced networks spectral and energy efficiency at lower operational and maintenance costs;

vi Singapore has committed to reducing GHG emissions remarkably by 2030. The buildings sector, which consumes more than one-third of the country's total electricity, can play a major role in reducing the carbon footprint upon implementing the concept of smart cities, mitigating climate change.

vii In short, the new 5G network technology will have substantial positive influence on energy, waste, risk, water resources, and economic management, thereby leading to more sustainability with lower climate change impacts.

Author Contributions: Conceptualization, G.F.H. and K.W.S.; methodology, G.F.H.; software, K.W.S.; validation, G.F.H.; formal analysis, G.F.H.; investigation, K.W.S.; resources, G.F.H.; data curation, G.F.H.; writing—original draft preparation, G.F.H.; writing—review and editing, K.W.S.; visualization, G.F.H.; supervision, K.W.S.; project administration, K.W.S.; funding acquisition, K.W.S. Both authors have read and agreed to the published version of the manuscript.

Funding: This research received no external funding.

Institutional Review Board Statement: Not applicable.

Informed Consent Statement: Not applicable.

Data Availability Statement: Data is contained within the article.

Acknowledgments: Authors would like to thank the National University of Singapore for their support in conducting this research.

Conflicts of Interest: The authors declare no conflict of interest.

Abbreviations

GHGs	Global greenhouse gases
IoT	Internet of things
NZE	Net zero energy
NUS	National University of Singapore
CO_2	Carbon dioxide emission
NH_4	methane
MEWR	Ministry of the environment and water resources
IWMF	Integrated waste management facility
SGS	Singapore smart garbage system
SGBs	Smart garbage bins
ILFI	international living future institute
GPS	Global positioning system
NEA	national environment agency
ICRM	Institute for Catastrophe Risk Management

References

1. De Coninck, H.C. IPCC SR15: Summary for Policymakers. In *IPCC Special Report Global Warming of 1.5 °C*; Intergovernmental Panel on Climate Change: Geneva, Switzerland, 2018.
2. Cobacho, S.P.; Wanke, S.; Konstantinou, Z.; El Serafy, G. Impacts of shellfish reef management on the provision of ecosystem services resulting from climate change in the Dutch Wadden Sea. *Mar. Policy* **2020**, *119*, 104058. [CrossRef]
3. Shah, K.W.; Huseien, G.F. Biomimetic Self-Healing Cementitious Construction Materials for Smart Buildings. *Biomimetics* **2020**, *5*, 47. [CrossRef]
4. Huseien, G.F.; Mirza, J.; Ismail, M.; Ghoshal, S.K.; Hussein, A.A. Geopolymer mortars as sustainable repair material: A comprehensive review. *Renew. Sustain. Energy Rev.* **2017**, *80*, 54–74. [CrossRef]
5. Goldberg, M.H.; Gustafson, A.; van der Linden, S. Leveraging Social Science to Generate Lasting Engagement with Climate Change Solutions. *One Earth* **2020**, *3*, 314–324. [CrossRef]
6. Taillardat, P.; Thompson, B.S.; Garneau, M.; Trottier, K.; Friess, D.A. Climate change mitigation potential of wetlands and the cost-effectiveness of their restoration. *Interface Focus* **2020**, *10*, 20190129. [CrossRef] [PubMed]

7. Masson-Delmotte, V.; Zhai, P.; Pörtner, H.-O.; Roberts, D.; Skea, J.; Shukla, P.R. ShuklaGlobal warming of 1.5 °C. An IPCC Special Report on the impacts of global warming of 1.5 °C above pre-industrial levels and related global greenhouse gas emission pathways, in the context of strengthening the global response to the threat of climate change, sustainable development, and efforts to eradicate poverty. *Sustain. Dev. Efforts Eradicate Poverty* **2018**, *1*, 1–9.
8. Cabeza, L.F.; Barreneche, C.; Miró, L.; Morera, J.M.; Bartolí, E.; Fernández, A.I. Low carbon and low embodied energy materials in buildings: A review. *Renew. Sustain. Energy Rev.* **2013**, *23*, 536–542. [CrossRef]
9. Archer, D. *The Long Thaw: How Humans Are Changing the Next 100,000 Years of Earth's Climate*; Princeton University Press: Princeton, NJ, USA, 2016; Volume 44.
10. Ruddiman, W.F. The anthropogenic greenhouse era began thousands of years ago. *Clim. Chang.* **2003**, *61*, 261–293. [CrossRef]
11. Kennedy, C.; Steinberger, J.; Gasson, B.; Hansen, Y.; Hillman, T.; Havranek, M.; Mendez, G.V. *Greenhouse Gas. Emissions from Global Cities*; ACS Publications: Washington, DC, USA, 2009.
12. Olivier, J.G.; Schure, K.; Peters, J. *Trends in Global CO_2 and Total Greenhouse Gas. Emissions*; PBL Netherlands Environmental Assessment Agency: Hague, The Netherlands, 2017; Volume 5.
13. Williams, J.H.; DeBenedictis, A.; Ghanadan, R.; Mahone, A.; Moore, J.; Morrow, W.R.; Torn, M.S. The technology path to deep greenhouse gas emissions cuts by 2050: The pivotal role of electricity. *Science* **2012**, *335*, 53–59. [CrossRef]
14. Birch, E.L.; Wachter, S.M. *Global Urbanization*; University of Pennsylvania Press: Philadelphia, PA, USA, 2011.
15. Jin, J.; Gubbi, J.; Marusic, S.; Palaniswami, M. An information framework for creating a smart city through internet of things. *IEEE Internet Things J.* **2014**, *1*, 112–121. [CrossRef]
16. Hammi, B.; Khatoun, R.; Zeadally, S.; Fayad, A.; Khoukhi, L. IoT technologies for smart cities. *IET Netw.* **2017**, *7*, 1–13. [CrossRef]
17. Scuotto, V.; Ferraris, A.; Bresciani, S. Internet of Things: Applications and challenges in smart cities. A case study of IBM smart city projects. *Bus. Process. Manag. J.* **2016**. [CrossRef]
18. Nnaji, C.C.; Utsev, J.T. Climate Change and Waste Management: A Balanced Assessment. *J. Sustain. Dev. Afr.* **2011**, *13*, 17–34.
19. Rosenzweig, C.; Iglesius, A.; Yang, X.B.; Epstein, P.R.; Chivian, E. Climate change and extreme weather events-Implications for food production, plant diseases, and pests. *Glob. Chang. Hum. Health* **2001**, *2*, 90–94. [CrossRef]
20. Hoegh-Guldberg, O.; Bruno, J.F. The impact of climate change on the world's marine ecosystems. *Science* **2010**, *328*, 1523–1528. [CrossRef]
21. Leibensperger, E.; Mickley, L.J.; Jacob, D.J.; Chen, W.T.; Seinfeld, J.H.; Nenes, A.; Rind, D. Climatic effects of 1950–2050 changes in US anthropogenic aerosols—Part 2: Climate response. *Atmos. Chem. Phys.* **2012**, *12*, 3349–3362. [CrossRef]
22. Rosenberg, S.; Vedlitz, A.; Cowman, D.F.; Zahran, S. Climate change: A profile of US climate scientists' perspectives. *Clim. Chang.* **2010**, *101*, 311–329. [CrossRef]
23. Boemare, C.; Quirion, P. Implementing greenhouse gas trading in Europe: Lessons from economic literature and international experiences. *Ecol. Econ.* **2002**, *43*, 213–230. [CrossRef]
24. Binti Sa'adin, S.L.; Kaewunruen, S.; Jaroszweski, D. Risks of Climate Change with Respect to the Singapore-Malaysia High Speed Rail System. *Climate* **2016**, *4*, 65. [CrossRef]
25. Paudel, P.; Bhattarai, A. 5G telecommunication technology: History, overview, requirements and use case scenario in context of Nepal. In Proceedings of the ICT4D Conference, Lusaka, Zambia, 30 April–2 May 2018.
26. Ahad, M.A.; Paiva, S.; Tripathi, G.; Feroz, N. Enabling Technologies and Sustainable Smart Cities. *Sustain. Cities Soc.* **2020**, *61*, 102301. [CrossRef]
27. Jia, M.; Komeily, A.; Wang, Y.; Srinivasan, R.S. Adopting Internet of Things for the development of smart buildings: A review of enabling technologies and applications. *Autom. Constr.* **2019**, *101*, 111–126. [CrossRef]
28. Ullah, Z.; Al-Turjman, F.; Mostarda, L.; Gagliardi, R. Applications of Artificial Intelligence and Machine learning in smart cities. *Comput. Commun.* **2020**, *154*, 313–323. [CrossRef]
29. Chew, M.Y.L.; Teo, E.A.L.; Shah, K.W.; Kumar, V.; Hussein, G.F. Evaluating the Roadmap of 5G Technology Implementation for Smart Building and Facilities Management in Singapore. *Sustainability* **2020**, *12*, 10259. [CrossRef]
30. United States Environmental Protection Agency. *Inventory of US Greenhouse Gas. Emissions and Sinks: 1990–2011*; United States Environmental Protection Agency: Washington, DC, USA, 2013; Volume 505.
31. Moradkhani, E. Climate Change and Energy Management Strategies. *Comput. Water Energy Environ. Eng.* **2017**, *6*, 143–153. [CrossRef]
32. Dovì, V.G.; Friedler, F.; Huisingh, D.; Klemeš, J.J. Cleaner energy for sustainable future. *J. Clean. Prod.* **2009**, *17*, 889–895. [CrossRef]
33. Deng, S.; Wang, R.; Dai, Y. How to evaluate performance of net zero energy building—A literature research. *Energy* **2014**, *71*, 1–16. [CrossRef]
34. D'Agostino, D.; Mazzarella, L. What is a Nearly zero energy building? Overview, implementation and comparison of definitions. *J. Build. Eng.* **2019**, *21*, 200–212. [CrossRef]
35. Alaloul, W.S.; Musarat, M.A. Impact of Zero Energy Building: Sustainability Perspective. In *Sustainable Sewage Sludge Management and Resource Efficiency*; IntechOpen: London, UK, 2020.
36. Marjaba, G.; Chidiac, S. Sustainability and resiliency metrics for buildings—Critical review. *Build. Environ.* **2016**, *101*, 116–125. [CrossRef]
37. Doan, D.T.; Ghaffarianhoseini, A.; Naismith, N.; Zhang, T.; Ghaffarianhoseini, A.; Tookey, J. A critical comparison of green building rating systems. *Build. Environ.* **2017**, *123*, 243–260. [CrossRef]

38. Wong, J.K.W.; Zhou, J. Enhancing environmental sustainability over building life cycles through green BIM: A review. *Autom. Constr.* **2015**, *57*, 156–165. [CrossRef]
39. Azhar, S.; Carlton, W.A.; Olsen, D.; Ahmad, I. Building information modeling for sustainable design and LEED® rating analysis. *Autom. Constr.* **2011**, *20*, 217–224. [CrossRef]
40. Perlova, E.; Platonova, M.; Gorshkov, A.; Rakova, X. Concept project of zero energy building. *Procedia Eng.* **2015**, *100*, 1505–1514. [CrossRef]
41. Fedorczak-Cisak, M.; Furtak, M.; Gintowt, J.; Kowalska-Koczwara, A.; Pachla, F.; Stypuła, K.; Tatara, T. Thermal and vibration comfort analysis of a nearly zero-energy building in Poland. *Sustainability* **2018**, *10*, 3774. [CrossRef]
42. Baden, S.; Fairey, P.; Waide, P.; de T'serclaes, P.; Laustsen, J. Hurdling financial barriers to low energy buildings: Experiences from the USA and Europe on financial incentives and monetizing building energy savings in private investment decisions. In Proceedings of the 2006 ACEEE Summer Study on Energy Efficiency in Buildings, Washington, DC, USA, 26 August 2006.
43. Marszal, A.J.; Heiselberg, P.; Bourrelle, J.S.; Musall, E.; Voss, K.; Sartori, I.; Napolitano, A. Zero Energy Building—A review of definitions and calculation methodologies. *Energy Build.* **2011**, *43*, 971–979. [CrossRef]
44. Attia, S. *Net Zero Energy Buildings (NZEB): Concepts, Frameworks and Roadmap for Project Analysis and Implementation*; Butterworth-Heinemann: Oxford, UK, 2018.
45. Onyanta, A. Cities, municipal solid waste management, and climate change: Perspectives from the South. *Geogr. Compass* **2016**, *10*, 499–513. [CrossRef]
46. Kweku, D.W.; Bismark, O.; Maxwell, A.; Desmond, K.A.; Danso, K.B.; Oti-Mensah, E.A.; Adormaa, B.B. Greenhouse effect: Greenhouse gases and their impact on global warming. *J. Sci. Res. Rep.* **2017**, 1–9. [CrossRef]
47. Soussana, J.-F.; Allard, V.; Pilegaard, K.; Ambus, P.; Amman, C.; Campbell, C.; Valentini, R. Full accounting of the greenhouse gas (CO_2, N_2O, CH_4) budget of nine European grassland sites. *Agric. Ecosyst. Environ.* **2007**, *121*, 121–134. [CrossRef]
48. Bogner, J.; Pipatti, R.; Hashimoto, S.; Diaz, C.; Mareckova, K.; Diaz, L.; Gregory, R. Mitigation of global greenhouse gas emissions from waste: Conclusions and strategies from the Intergovernmental Panel on Climate Change (IPCC) Fourth Assessment Report. Working Group III (Mitigation). *Waste Manag. Res.* **2008**, *26*, 11–32. [CrossRef]
49. De Cara, S.; Houzé, M.; Jayet, P.-A. Methane and nitrous oxide emissions from agriculture in the EU: A spatial assessment of sources and abatement costs. *Environ. Resour. Econ.* **2005**, *32*, 551–583. [CrossRef]
50. Kula, E. *Economics of Natural Resources, the Environment and Policies*; Springer Science & Business Media: Berlin/Heidelberg, Germany, 2012.
51. Beaver, J.R.; Manis, E.E.; Loftin, K.A.; Graham, J.L.; Pollard, A.I.; Mitchell, R.M. Land use patterns, ecoregion, and microcystin relationships in US lakes and reservoirs: A preliminary evaluation. *Harmful Algae* **2014**, *36*, 57–62. [CrossRef]
52. Beard, S.; Holt, L.; Tzachor, A.; Kemp, L.; Avin, S.; Torres, P.; Belfield, H. Assessing climate change's contribution to global catastrophic risk. *Futures* **2021**, *127*, 102673. [CrossRef]
53. Robinson, B.H. E-waste: An assessment of global production and environmental impacts. *Sci. Total Environ.* **2009**, *408*, 183–191. [CrossRef]
54. Esmaeilian, B.; Wang, B.; Lewis, K.; Duarte, F.; Ratti, C.; Behdad, S. The future of waste management in smart and sustainable cities: A review and concept paper. *Waste Manag.* **2018**, *81*, 177–195. [CrossRef]
55. Mdukaza, S.; Isong, B.; Dladlu, N.; Abu-Mahfouz, A.M. Analysis of IoT-enabled solutions in smart waste management. In Proceedings of the IECON 2018-44th Annual Conference of the IEEE Industrial Electronics Society, Washington, DC, USA, 21–23 October 2018.
56. SBallal, V.; Patil, S.S.; Dange, N.P. Smart City Waste Management System using IoT SERVER. *Management* **2019**, *6*, 955–958.
57. Ng, B.J.H.; Mao, Y.; Chen, C.L.; Rajagopal, R.; Wang, J.Y. Municipal food waste management in Singapore: Practices, challenges and recommendations. *J. Mater. Cycles Waste Manag.* **2017**, *19*, 560–569. [CrossRef]
58. Mehmood, Y.; Ahmad, F.; Yaqoob, I.; Adnane, A.; Imran, M.; Guizani, S. Internet-of-things-based smart cities: Recent advances and challenges. *IEEE Commun. Mag.* **2017**, *55*, 16–24. [CrossRef]
59. Bharadwaj, A.S.; Rego, R.; Chowdhury, A. IoT based solid waste management system: A conceptual approach with an architectural solution as a smart city application. In Proceedings of the 2016 IEEE Annual India Conference (INDICON), Bangalore, India, 16–18 December 2016.
60. Shirke, S.; Ithape, S.; Lungase, S.; Mohare, M. Automation of smart waste management using IoT. *Int. Res. J. Eng. Technol.* **2019**, *6*, 414–419.
61. Shahinzadeh, H.; Mirhedayati, A.S.; Shaneh, M.; Nafisi, H.; Gharehpetian, G.B.; Moradi, J. IoT architecture for smart grids. In Proceedings of the 2019 International Conference on Protection and Automation of Power System (IPAPS), Tehran, Iran, 8–9 January 2019.
62. Chaudhari, M.S.; Patil, B.; Raut, V. IoT based Waste Collection Management System for Smart Cities: An Overview. In Proceedings of the 2019 3rd International Conference on Computing Methodologies and Communication (ICCMC), Erode, India, 27–29 March 2019.
63. Abbaspour, K.C.; Faramarzi, M.; Ghasemi, S.S.; Yang, H. Assessing the impact of climate change on water resources in Iran. *Water Resour. Res.* **2009**, *45*. [CrossRef]
64. DeNicola, E.; Aburizaiza, O.S.; Siddique, A.; Khwaja, H.; Carpenter, D.O. Climate change and water scarcity: The case of Saudi Arabia. *Ann. Glob. Health* **2015**, *81*, 342–353. [CrossRef]

65. Babel, M.S.; Bhusal, S.P.; Wahid, S.M.; Agarwal, A. Climate change and water resources in the Bagmati River Basin, Nepal. *Theor. Appl. Climatol.* **2014**, *115*, 639–654. [CrossRef]
66. Mahmood, R.; Jia, S.; Babel, M.S. Potential impacts of climate change on water resources in the Kunhar River Basin, Pakistan. *Water* **2016**, *8*, 23. [CrossRef]
67. Wadekar, S.; Vakare, V.; Prajapati, R.; Yadav, S.; Yadav, V. Smart water management using IOT. In Proceedings of the 2016 5th International Conference on Wireless Networks and Embedded Systems (WECON), Rajpura, India, 14–16 October 2016.
68. Rajurkar, C.; Prabaharan, S.; Muthulakshmi, S. IoT based water management. In Proceedings of the 2017 International Conference on Nextgen Electronic Technologies: Silicon to Software (ICNETS2), Chennai, India, 23–25 March 2017.
69. Pincheira, M.; Vecchio, M.; Giaffreda, R.; Kanhere, S.S. Exploiting constrained IoT devices in a trustless blockchain-based water management system. In Proceedings of the 2020 IEEE International Conference on Blockchain and Cryptocurrency (ICBC), Toronto, ON, Canada, 2–6 May 2020.
70. Sekaran, K.; Meqdad, M.N.; Kumar, P.; Rajan, S.; Kadry, S. Smart agriculture management system using internet of things. *Telkomnika* **2020**, *18*, 1275–1284. [CrossRef]
71. Hu, X.; Qian, S. IoT application system with crop growth models in facility agriculture. In Proceedings of the 2011 6th International Conference on Computer Sciences and Convergence Information Technology (ICCIT), Seogwipo, Korea, 29 November–2 December 2011.
72. Bing, F. Research on the agriculture intelligent system based on IOT. In Proceedings of the 2012 International Conference on Image Analysis and Signal Processing, Hangzhou, China, 9–11 November 2012.
73. Wang, C.; Daneshmand, M.; Dohler, M.; Mao, X.; Hu, R.Q.; Wang, H. Guest Editorial-Special issue on internet of things (IoT): Architecture, protocols and services. *IEEE Sens. J.* **2013**, *13*, 3505–3510. [CrossRef]
74. Wang, C.; Bi, Z.; da Xu, L. IoT and cloud computing in automation of assembly modeling systems. *IEEE Trans. Ind. Inform.* **2014**, *10*, 1426–1434. [CrossRef]
75. Zhang, X.; Zhang, J.; Li, L.; Zhang, Y.; Yang, G. Monitoring citrus soil moisture and nutrients using an iot based system. *Sensors* **2017**, *17*, 447. [CrossRef] [PubMed]
76. Kim, S.; Lee, M.; Shin, C. IoT-based strawberry disease prediction system for smart farming. *Sensors* **2018**, *18*, 4051. [CrossRef]
77. Tuli, A.; Hasteer, N.; Sharma, M.; Bansal, A. Framework to leverage cloud for the modernization of the Indian agriculture system. In Proceedings of the IEEE International Conference on Electro/Information Technology, Milwaukee, WI, USA, 5–7 June 2014.
78. Zhao, J.-C.; Zhang, J.F.; Feng, Y.; Guo, J.X. The study and application of the IOT technology in agriculture. In Proceedings of the 2010 3rd International Conference on Computer Science and Information Technology, Chengdu, China, 9–11 July 2010.
79. Ning, H.; Wang, Z. Future internet of things architecture: Like mankind neural system or social organization framework? *IEEE Commun. Lett.* **2011**, *15*, 461–463. [CrossRef]
80. Yan-e, D. Design of intelligent agriculture management information system based on IoT. In Proceedings of the 2011 Fourth International Conference on Intelligent Computation Technology and Automation, Shenzhen, China, 28–29 March 2011.
81. Ma, J.; Zhou, X.; Li, S.; Li, Z. Connecting agriculture to the internet of things through sensor networks. In Proceedings of the 2011 International Conference on Internet of Things and 4th International Conference on Cyber, Physical and Social Computing, Dalian, China, 19–22 October 2011.
82. Kunreuther, H.; Heal, G.; Allen, M.; Edenhofer, O.; Field, C.B.; Yohe, G. Risk management and climate change. *Nat. Clim. Chang.* **2013**, *3*, 447–450. [CrossRef]
83. Aldunce, P.; Beilin, R.; Howden, M.; Handmer, J. Resilience for disaster risk management in a changing climate: Practitioners' frames and practices. *Glob. Environ. Chang.* **2015**, *30*, 1–11. [CrossRef]
84. Davis, S.J.; Lewis, N.S.; Shaner, M.; Aggarwal, S.; Arent, D.; Azevedo, I.L.; Benson, S.M.; Bradley, T.; Brouwer, J.; Chiang, Y.-M.; et al. Net-zero emissions energy systems. *Science* **2018**, *360*, 6396. [CrossRef]
85. Malik, V.; Singh, S. *Internet of Things: Risk Management, in Smart Systems and IoT: Innovations in Computing*; Springer: Berlin/Heidelberg, Germany, 2020; pp. 419–427.
86. Tol, R.S. The economic impacts of climate change. *Rev. Environ. Econ. Policy* **2018**, *12*, 4–25. [CrossRef]
87. Venkatramanan, V.; Shah, S.; Prasad, R. *Global Climate Change: Resilient and Smart Agriculture*; Springer: Berlin/Heidelberg, Germany, 2020.
88. Alliance, N. *5G White Paper. Next Generation Mobile Networks*; White Paper; NGMN: Frankfurt, Germany, 2015; Volume 1.
89. Markopoulos, I.; Valcarenghi, L.; Mesogiti, I.; Taferner, M.; Boleguin, P.; Bouali, F.; Cattoni, A. *The 5G Infrastructure Public Private Partnership (5G PPP) White Paper on "Service Performance Measurement Methods over 5G Experimental Networks"*; Coventry University: London, UK, 2021.
90. Del Rio, D.D.F.; Sovacool, B.K.; Bergman, N.; Makuch, K.E. Critically reviewing smart home technology applications and business models in Europe. *Energy Policy* **2020**, *144*, 111631. [CrossRef]
91. Daissaoui, A.; Boulmakoul, A.; Karim, L.; Lbath, A. IoT and Big Data Analytics for Smart Buildings: A Survey. *Procedia Comput. Sci.* **2020**, *170*, 161–168. [CrossRef]
92. D'Elia, A.; Roffia, L.; Zamagni, G.; Vergari, F.; Bellavista, P.; Toninelli, A.; Mattarozzi, S. Smart applications for the maintenance of large buildings: How to achieve ontology-based interoperability at the information level. In Proceedings of the The IEEE symposium on Computers and Communications, Riccione, Italy, 22–25 June 2010.

93. Chunjiang, Y. Development of a smart home control system based on mobile internet technology. *Int. J. Smart Home* **2016**, *10*, 293–300. [CrossRef]
94. Viswanath, S.K.; Yuen, C.; Tushar, W.; Li, W.T.; Wen, C.K.; Hu, K.; Liu, X. System design of the internet of things for residential smart grid. *IEEE Wirel. Commun.* **2016**, *23*, 90–98. [CrossRef]
95. Mak, K.-K.; Pichika, M.R. Artificial intelligence in drug development: Present status and future prospects. *Drug Discov. Today* **2019**, *24*, 773–780. [CrossRef] [PubMed]
96. Newaz, A.I.; Sikder, A.K.; Rahman, M.A.; Uluagac, A.S. Healthguard: A machine learning-based security framework for smart healthcare systems. In Proceedings of the 2019 Sixth International Conference on Social Networks Analysis, Management and Security (SNAMS), Granada, Spain, 22–25 October 2019.
97. Kim, J.; Jo, G.; Jeong, J. A Novel CPPS Architecture Integrated with Centralized OPC UA server for 5G-based Smart Manufacturing. *Procedia Comput. Sci.* **2019**, *155*, 113–120. [CrossRef]
98. Åkerman, M.; Lundgren, C.; Bärring, M.; Folkesson, M.; Berggren, V.; Stahre, J.; Friis, M. Challenges building a data value chain to enable data-driven decisions: A predictive maintenance case in 5G-Enabled manufacturing. *Procedia Manuf.* **2018**, *17*, 411–418. [CrossRef]
99. Walia, J.S.; Hämmäinen, H.; Kilkki, K.; Yrjölä, S. 5G network slicing strategies for a smart factory. *Comput. Ind.* **2019**, *111*, 108–120. [CrossRef]
100. Orange, J.S.-B.; Armada, A.G.; Evans, B.; Galis, A.; Karl, H. *White Paper for Research beyond 5G*; Final Edit; Networld (NW), NGMN: Frankfurt, Germany, 2020; pp. 1–43.