smart cities

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Review

Review of Smart City Energy Modeling in Southeast Asia

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Abstract: The Southeast Asian region has been eagerly exploring the concepts of smart city initiatives in recent years due to the enormous opportunities and potential. The initiatives are in line with their plan to promote energy efficiency, phase down/out fossil fuel-based generation, and reduce greenhouse gas emission intensity and electrification of various sectors in addition to renewable energy targets and policies to achieve net zero emissions by 2050 or 2060. However, the major challenges for these countries are related to leadership, governance, citizen support, investment, human capacity, smart device heterogeneity, and efficient modeling and management of resources, especially the energy systems. An intelligent energy system is one of the most significant components for any functional smart city, where artificial intelligence (AI), the internet of things (IoT), and big data are expected to tackle various existing and evolving challenges. This article starts with a brief discussion of smart city concepts and implementation challenges. Then, it identifies different types of smart city initiatives in Southeast Asian countries focusing on energy systems. In addition, the article investigates the status of smart systems in energy generation and storage, infrastructure, and model development. It identifies the unique challenges of these countries in implementing smart energy systems. It critically reviews many available energy modeling approaches and addresses their limitations and strengths, focusing on the region. Moreover, it also provides a preliminary framework for a successful energy system that exploits AI, IoT, and big data. Finally, the roadmap for a successful energy system requires appropriate policy development, innovative technological solutions, human capacity building, and enhancement of the effectiveness of current energy systems.

Keywords: challenges; efficient energy management; energy modeling; overview; renewable energy; smart city

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1. Introduction

A smart or intelligent city is built on the perfect combination of endowments and self-decisive activities, where an independent, sustainable, and efficient urban center ensures a high quality of living standards for the citizens through the optimal management of the available resources by resolving urban challenges through innovations [1–4]. The smart city should: (i) be high energy and resource-efficient; (ii) be progressively powered by clean and sustainable energy sources; (iii) rely on resilient and integrated resources and systems; (iv) possess better transportation and mobility facilities; (v) provide the participatory governance systems; (vi) ensure the highest level of safety for the people; (vii) foster innovative approaches for strategic planning. In the smart city, the common means of meeting the mentioned objectives are advanced and sophisticated information and communication technologies [5–11]. The smart city concept is becoming popular and is being adopted by decision makers throughout the world as the quality of life of citizens is being enhanced significantly.

The United Nations reported that two-thirds of the world's population live in urban areas. According to a few reports, Asia and Africa will be leading the urbanization process by 2050 with the projected figures of 64 and 56% of urban areas, respectively, due to the surging population growth of the mentioned continents [12–14]. However, with growing attention towards sustainability, climate change, and global warming issues, efficient smart city energy systems' management is considered a critically important challenge [15]. Considering the phenomena, scientists and scholars have been putting their efforts into developing advanced and realistic management and modeling approaches for efficient energy utilization in smart cities. Optimization, simulation, and equilibrium tools or models are the three most common methodological approaches to energy system modeling. The optimization model considers the design optimization of the endogenous system. Given that optimization tools are frequently used in city energy systems' assessment, it may be challenging to understand the findings owing to their complexity, which may somewhat compromise the reliability of the results. As an increase in model complexity is not a guarantee of improved accuracy, some conclusions have previously been drawn regarding the properties of these tools [16]. Uncertainties and variances can significantly impact the performance of energy systems in the inputs utilized in simulation models of low-carbon energy systems. Top-down equilibrium models revealed significant sensitivity when evaluating the integration of renewable energy sources and may need to be improved or used as a component of integrated mixed models [17].

Figure 1 illustrates a generic energy-system model with essential inputs and expected outputs, adopting a proper methodology [18–20]. The community energy management system (CEMS) runs, monitors, and controls the energy dynamics in the smart city through advanced coordination with the building energy management system (BEMS), home energy management system (HEMS), and factory energy management system (FEMS). Renewable and non-renewable energy generation units, electric vehicles and associated infrastructures, and electricity grids are also considered as integral parts of the CEMS [21]. Many countries have adopted the smart city concept that has emerged worldwide. However, there are many challenges to implementing the concept in Southeast Asia, including a lack of: investments, smart visionary leadership and governance, support from the citizens, and overall awareness of optimal management and modeling of the available resources [22–25]. Furthermore, the region is facing challenges in attaining renewable-energy generation targets due to the non-intervening authority of the regional cooperation organization and a high dependency on traditional energy resources and oil subsidies [26].

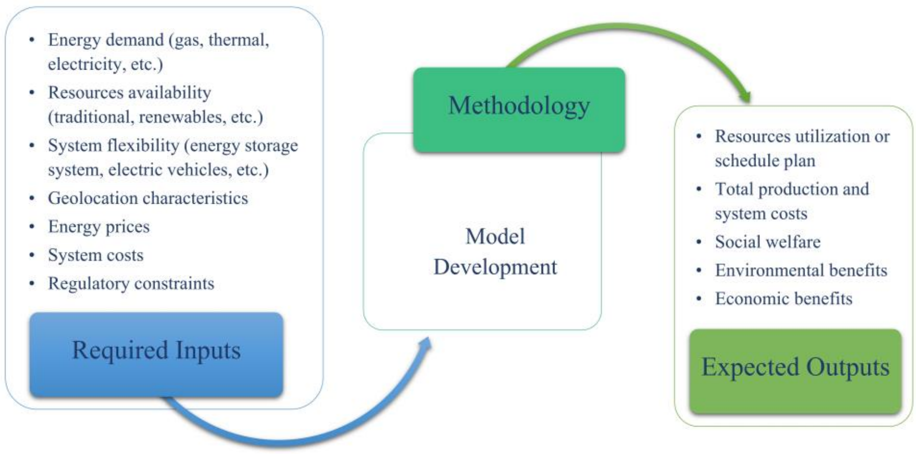

Figure 1. Schematic diagram of a generic energy system model [18–20].

Furthermore, as per an International Energy Agency (IEA) report, the surging growth of energy demand will make the region one of the critical drivers of world energy trends over the next 20 years [27]. Such growth in energy demand reflects the region's economic rise that simultaneously increases the challenges for the decision makers. Therefore, smart energy management is not an option for the region. Instead, the decision makers of the region need to overcome all obstacles to ensure the region's predicted economic growth and overall wellbeing. The IEA has also suggested essential pillars for the sustainable management of energy in the region that includes: (i) scaling up the renewable energy deployment massively by leveraging its bioenergy potential; (ii) putting major efforts into energy efficiency enhancement, especially in the fast-growing sectors; (iii) phasing out subsidies on the fossil fuel consumption; (iv) adopting carbon capture, utilization, and storage technologies to tackle important issues related to greenhouse gas (GHG) emissions. In this regard, implementing the smart city concept is inevitable for the region, where efficient energy management and modeling is one of the critical enablers.

Considering the mentioned notes, the region's researchers are putting their efforts into proposing sustainable energy management strategies. However, to the best of the authors' knowledge, comprehensive review articles on smart city energy modeling in Southeast Asia are not readily available and are rarely found. Therefore, this article aims to assist stakeholders, policymakers, and researchers in designing energy models for smart cities in Southeast Asia by providing strategies for effectively modeling and managing energy systems by reviewing the existing models in the literature. The specific contributions of the article are:

- This article reviews and analyzes the smart city concepts, implementation challenges, sustainable energy management, and modeling strategies.
- It briefly introduces the relevant software packages and their applications in modeling energy systems for smart cities.
- It also discusses the latest advancements and deployment of AI, IoT, and big data applications in modeling and managing smart city energy systems.
- Finally, it provides future research directions for the relevant research communities and guidelines for the stakeholders and policymakers in designing/adopting appropriate energy models for Southeast Asian smart cities.

The rest of the article structure is as follows: Section 2 presents the research methodology, whereas Section 3 briefly introduces the smart city concepts and relevant energy models. In Section 4, smart city energy modeling challenges and prospects in the context of the Southeast Asian region are illustrated. A futuristic approach to a smart city is presented in Section 5. Finally, the concluding remarks and recommendations are provided in Section 6.

2. Review Methodology

The methodological framework that Brocke et al. [28] suggested in their study regarding the significance of rigor in recording the literature search process was used to conduct the literature review on smart city energy modeling in Southeast Asia. The five-phase framework for the literature search process serves as the foundation for this methodological approach. These steps are: (i) review scope definition, (ii) conceptualization of the topic, (iii) the literature search, (iv) the literature analysis and synthesis, and (v) the research agenda.

2.1. Review Scope Definition

The authors refer to a standard taxonomy provided by Cooper [29] that comprises six features for the literature survey to precisely identify the scope of this study of the literature:

(a) Focus is the primary interest area for the reviewers. This section may be concerned with study findings, research procedures, theories, practices, or applications. The literature search area is concerned with all kinds of articles, from theoretical to application-focused ones.

(b) Goal refers to the author's expectations for the review. For example, the purpose of the literature review could be to integrate, critique, and focus on the central issue.
(c) Organization refers to the way a reviewer sets up his search strategy. For example, the literature review might be arranged in one of three ways: chronologically, conceptually, or methodologically. This literature is organized chronologically first, followed by conceptual order.
(d) Perspective is the stance of the reviewer while analyzing the literature. The reviewer may begin the research by taking either a neutral or pro-position stance. The authors believe it is helpful to take a primarily unbiased literature search viewpoint since there is no desire to pursue any opinion on the subject.
(e) Audience refers to the demographics to which the review is directed. For example, the audience for the literature study includes industrial decision makers and professional academics.
(f) Coverage refers to how the reviewer conducts his search of the literature and how he decides whether materials are appropriate and of high quality. The author chose a suitably representative coverage out of the following options: exhaustive, exhaustive with selected citation, representative, central, or pivotal.

2.2. Topic Conceptualization

A review should start with a comprehensive understanding of what is known about the subject and any potential knowledge gaps, according to Ref. [28]. Consequently, to select the important topics on which to build the literature review, the authors started the study on the "smart city energy modeling in Southeast Asia" by searching for:

- A number of papers about the meaning of the word "smart", as "Smart City" is a broad concept that encompasses many aspects of urban life, including urban planning, sustainable development, environment, energy grid, economic development, technologies, social participation, and so on.
- Several papers about the challenges and implementations related to smart cities, especially in Southeast Asian countries.
- Several papers related to smart city components and energy modeling and tools.

2.3. The Literature Search, Analysis, and Synthesis

The authors examined the following search strategy phases to perform this search of the literature: (a) selecting the database source; (b) selecting keywords and search criteria; (c) deciding whether to apply backward and forward searches; (d) determining the adequacy of the literature subset. To examine the gathered literature methodically, this phase's goal was to arrange the searched and downloaded papers. This objective was achieved by organizing the 208 papers to be investigated about the time analysis, terminology analysis, methodology analysis, modeling analysis, and geographic analysis.

2.4. Research Agenda

The ultimate goal of this review of the literature is not only to review and analyze the concepts of smart cities, implementation issues, sustainable energy management, and modeling approaches but also to introduce the relevant software packages and their applications in modeling energy systems for smart cities, to discuss the most recent developments and deployment of AI, IoT, and big data applications in modeling and managing smart city energy systems, as well as to provide future research directions and guidelines to the research communities, stakeholders, and policymakers in designing/adopting appropriate energy models for the smart cities in Southeast Asia.

3. Smart City Concepts and Energy Models

The smart city concepts integrate information and communication technologies (ICT), collect information from various physical devices, and connect the citizens to optimize the operations and services efficiencies by utilizing the available resources for the wellbeing of the society. This section demonstrates the worldwide overview of smart city concepts and the implementation challenges in Southeast Asia.

3.1. Smart City Concept Overview

The smart city journey started in the 1970s in Los Angeles, when the first urban big data project was created. Amsterdam is non-arguably the first fully pledged smart city, with the creation of a virtual digital city in 1994. However, the concept received widespread attention in the mid-2000s after a massive advancement and deployment of communication technologies [30]. However, obtaining a precise definition of the smart city is difficult due to the adoption of various technologies and their breadth of implementation. One of the most popular definitions can be found in Ref. [31], which identifies the four key components: (i) adoption of a wide range of digital technologies for the communities, (ii) transformation of work and life through the use of ICT, (iii) embedding ICT throughout the entire city and its components, and (iv) territorialization of such practices to ICT and people together. As stated, different cities might need to adopt different approaches for implementing the smart city concepts, depending on the underlying challenges and issues that those cities strive to solve and the available infrastructures and resources of the cities. The city inhabitants also play essential roles in ensuring the success of smart city implementation. Summarily, the cities need to bring together the government, private sector, and academia to draft suitable and effective smart city strategies. Table 1 summarizes the emphasis, proposals, and targets of a few reported smart city concepts worldwide.

Table 1. Smart city concept overview.

Ref.	Study Area	Emphasis	Proposals	Targets
[32]	North America (San Diego, Chicago, New York, and Vancouver)	Intelligent buildings and streetlights; electrification of transportation; renewable energy resources-based model	Focusing on the local priorities and strengths of the cities; bringing together public, private, and academia	Zero emissions from new buildings; autonomous and shared transportation and mobility; smart grid implementation and disaster-ready energy infrastructure
[33]	Latin American countries and the Caribbean Islands	Technical readiness and viability	Development of an integral city process; collaboration between government, academia, and industry	Intelligent solutions for the local and federal governments by collecting international and regional experiences and expectations
[34]	Australia (Melbourne)	Core strategic drivers (GHG emissions and competitiveness)	Combining soft and hard infrastructures	Making the invisible visible, thus raising awareness about the urban infrastructure, activity, and ecosystem
[31,35]	Netherlands (Amsterdam)	Smart projects for energy savings	Bringing together the public authorities, proactive citizens, innovative companies, and knowledge institutions	Innovative solutions for metropolitan issues (social, economic, and ecological)
[36]	Spain (Barcelona)	Highly transformational data-driven technologies	Promoting the interests of citizens and maximizing the returns to the public	Development of a more sustainable and collaborative economy and society
[37]	France (Lyon) and Japan (Yokohama)	Bulk integration of renewable energy resources	Technical innovations and building public awareness for efficient consumption of energy	Reduction of 80% GHG emissions by 2050
[21]	Japan (Kitakyushu)	Smart grid implementation and recycling of the wastes	Cooperation between industry, government, and people; community-based energy management system development	Reduction of 50% GHG emissions in the near future
[38]	Saudi Arabia (NEOM)	A new model for sustainable living, working, and prospering	The first cognitive city that puts humans first and provides an unprecedented urban living experience while preserving the surrounding nature	A 100% renewable energy-powered city with no roads, cars, or emissions

Table 1. *Cont.*

Ref.	Study Area	Emphasis	Proposals	Targets
[39]	United Arab Emirates (Dubai)	Three impact axes: happiness, economic growth, and resource resilience	Four pillars: seamless, efficient, safe, and personalized	Reduction of environmental impact, easy access to social services, and use of disruptive technologies
[40]	China (44 pilot smart cities)	Understanding the strength and weaknesses of individual cities	Establishment of an intelligent evaluation mechanism and investment in smart infrastructure and development of human resources	Smart city performance improvement and attaining sustainability
[41]	Hong Kong City	Embracing innovation and technology	Addressing urban challenges, enhancing attractiveness, and inspiring continuous innovation and sustainable development	Building a world-famed city with a strong economy and high quality of living
[12]	ASEAN and Asia-Pacific countries.	High-speed broadband connection; smart and intelligent energy, water, and waste management systems	Collaboration between government, private entities, and people; resilient cyberinfrastructure and high-quality education	Reduction of vehicular emissions; efficient management of energy; enhancement of recycling rates; development of technology
[42]	Singapore (Singapore City)	Digital economy, digital government, and digital society	Encouraging the use of digital innovation and technology to drive sustainability and livability	Treating the city as a testbed for smart city models
[43]	Malaysia (Johor Bahru)	A computable general equilibrium model	Introduction of carbon tax policy	Economic development and GHG emission reduction
[44,45]	Thailand (Khon Kaen)	Upgradation of the standards of services and promotion of innovation	Availability of digital infrastructure and sustainable solutions	Development of a sustainable city for all people in the society
[46]	Brunei (Bandar Seri Begawan)	Facilitating the growth of the city	Promotion of vibrant social and cultural life through industrial development and innovation	Increase economic competitiveness and ensure high quality of life
	Cambodia (Battambang)	Achieving a socially responsible, environmentally friendly, and economical city	Building infrastructures ensuring environmental quality and appropriate human capital building	Digitalization of the enterprises through required skill development and rehabilitating the citizens to formal housing
	Indonesia (Jakarta)	A leading city of happy citizens	Building infrastructure through innovation and ensuring human health and wellbeing	Digitalization of the transportation sector and the creation of jobs through enterprise development
	Laos (Luang Prabang)	A clean, green, and livable environment	Development of efficient waste management systems and infrastructures	Restoring wetlands and preserving heritage sites
	Vietnam (Hanoi)	A green and culturally rich modern city with sustainable development	Smart transportation, travel, environment, and energy systems	Improving the quality of life by streamlining urban management and protecting the environment
	Philippines (Manila)	Bringing governance to the palms of the citizens	Improvement of safety, service, and education systems	Technological upgradation and integrated database development
	Myanmar (Yangon)	A city of blue, green, and gold.	Building infrastructures to promote tourism by ensuring social wellbeing	Improving formal settlement rate, supplying clean water, and developing sewer systems

3.2. Smart City Energy Model Components

The energy dynamics of smart cities are complex and abundant. However, the five major energy-related activities, including energy generation, storage, infrastructure, facilities, and transportation, are interlinked and commonly known as areas of intervention (Figure 2) [25]. Furthermore, most critical systems and components in smart cities are networked to obtain granular and sophisticated information to achieve higher operational efficiency by sharing and analyzing relevant and actionable information [47]. Therefore, this section briefly introduces the major energy model components of smart city initiatives.

3.2.1. Sustainable Energy Generation

The smart city concept starts with generating smart energy from clean and sustainable energy resources by redefining the energy mix and distribution system [48]. However, it is not possible to generate all the required energy from sustainable and renewable energy resources for the smart cities at the beginning of the initiatives. Still, the towns should gradually migrate to fully renewable energy-based schemes. Worldwide, 77 countries from 10 different regions covering around 100 cities committed to reducing their carbon emissions to zero by 2050, whereas many other cities committed to reducing their emissions by up to a certain percentage. Such commitments are driving the cities to adopt sustainable energy resources at a higher pace. For instance, as of 2020, modern renewables (excluding traditional uses of biomass) accounted for around 12.6% of total final energy consumption globally (only 8.7% in 2009) [49]. Figure 3 presents the renewable energy targets for major cities around the world [50]. As can be seen, more than 834 cities around the globe have 1088 renewable energy targets, where the North American and European regions represent the major share of the cities.

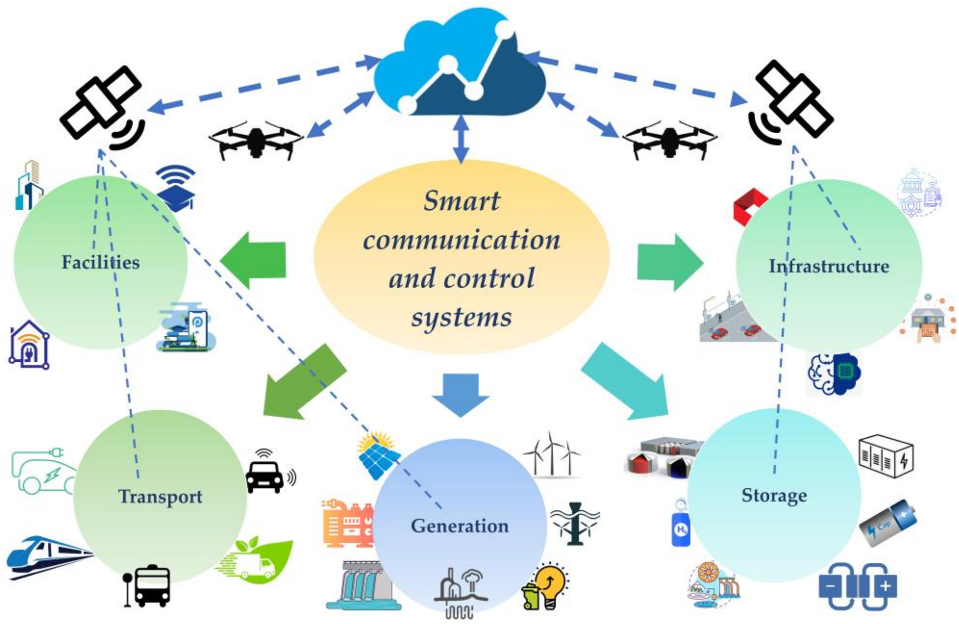

Figure 2. Smart city energy model components [25,51,52].

Solar energy is one of the major resources of clean and sustainable energy generation, where the main categories are solar photovoltaic (PV), concentrated solar power (CSP), and solar heating and cooling (SHC). Solar PV modules were primarily recommended for small-scale and remote installation and generation of energy due to their higher investment costs. However, enormous efforts and initiatives from the decision makers and the researchers reduced the manufacturing cost of the PV systems and, at the same time, increased their efficiency over the last few years due to various reasons, including climate change and shortage of fossil fuels [53–55]. Therefore, the industry has been installing and commissioning almost 100 GW of PV systems' capacity annually for the last couple of years and integrating large-scale systems into the electricity grids. In 2021, the global solar PV capacity reached 942 GW. On the other hand, global SHC and CSP capacities reached 522 GW and 6 GW, respectively [49]. Another solar energy generation approach, the photovoltaic thermal (PVT) system, combines solar PV and thermal collector systems. The PVT system exhibits superior performance due to its effective heat-removal process [56]. Therefore, these advanced solar energy technologies (PV, CSP, SHC, and PVT) can be considered as promising solutions for sustainable energy generation in smart cities at various scales and levels due to their advanced features, competitiveness, and affordability [57].

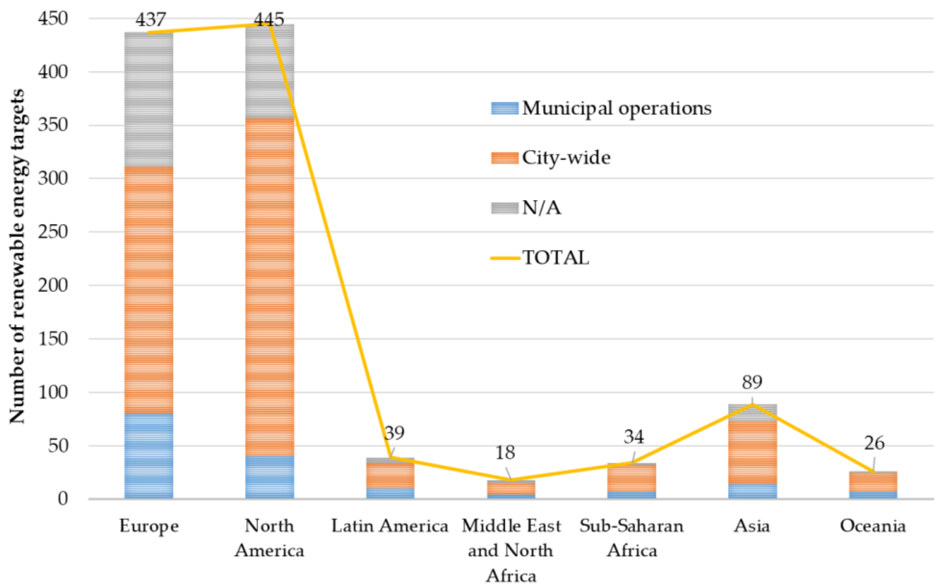

Figure 3. Number of renewable energy targets by the scale of application [50].

Wind energy generation is a mature sustainable technology that produces energy at a low price at the utility scale, both onshore and offshore [25]. In 2021, WT was one of the leading modern renewable energy generation technologies, with a global capacity of 845 GW [49]. The increasing trends, affordability, and availability of wind energy technology signal its inevitable share in smart city energy systems as a source of sustainable energy. Biomass, a versatile energy source, can be used directly to generate electricity or heat through direct combustion or indirect conversion to a gaseous or liquid biofuel [25]. Modern bioenergy contributed around 5.3% of the global final energy consumption in 2020, which is around 42.1% of the modern renewable energy share of the final energy consumption [49]. The most common alternative energy source is the traditional hydro energy that captures energy from fast-running or falling water. The global capacity of such an energy system was around 1197 GW in 2021 and contributed around 3.9% of global final energy consumption in 2020. Other renewable energy resource capacities have also been increasing over the years. For instance, geothermal and ocean power capacities reached 14.5 GW and 524 MW, respectively, in 2021 [49]. Waste-to-energy, another promising renewable energy resource, generates energy through electricity, heat, fuel, or other useable materials by treating the waste. The global market for this efficient and environmentally safe energy recovery system is expected to grow consistently in the coming decades [58]. All the mentioned sustainable energy resources can be integral parts of the smart city energy model based on their availability to reduce GHG emissions.

3.2.2. Energy Storage Systems

The surging growth of renewable energy technologies has generated new interest in energy storage systems (ESS). The ESS is considered the critical component of sustainable development due to its ability to mitigate power variations, enhance electric system flexibility and reliability, and store energy for future applications. Most large-scale deployed ESS are based on pumped-hydroelectric and compressed-air ESS. These two technologies represent around 3.0% of the total global generation capacity. Other types of ESS include super-capacitor, flywheels, batteries, electromechanical, electric vehicles, and superconducting magnetic energy storage systems [59–63]. As per the report of Wood Mackenzie, global energy storage capacity is expected to hit 741 GWh of cumulative capacity by 2030 [64]. Therefore, it is expected to have significant penetration in various ESS technologies in smart city energy models for multiple applications, including smoothing intermittency, shaving the peak demand, improving the resiliency of the electric grid, and increasing revenue. Figure 4 presents the comparison of battery storage capacity in major countries as of 2020, with that of the projected total for 2026. Over the following five years, it is anticipated that the installed storage capacity will increase by almost seven times, reaching over 158 GWh by 2026. There is a rising global demand for system flexibility and storage to properly utilize and integrate higher percentages of variable renewable energy into power networks [65].

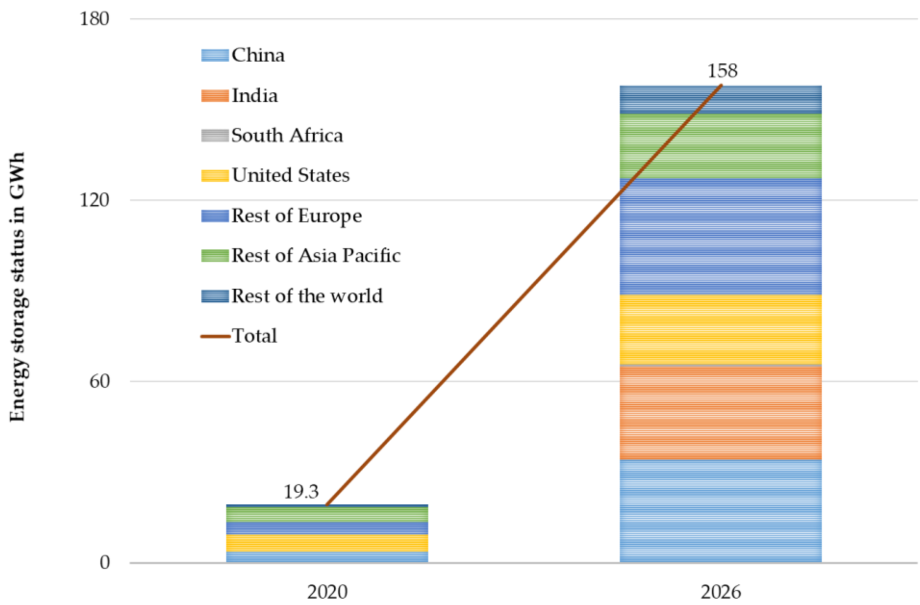

Figure 4. Battery storage capability by countries, 2020 and 2026 [65].

3.2.3. Smart Buildings and Smart Appliances

Intelligent buildings are the crucial elements of the smart city initiatives that provide an efficient environment by optimizing and combining the systems, structures, and services. Smart cities comprise residential and commercial buildings, along with small-scale infrastructure. The operational efficiencies of the smart city comprehensively depend on the buildings, as this sector consumes almost three-quarters of the city's energy. Hence, the effective utilization of energy in buildings by ensuring citizens' comfort levels is considered one of the most challenging tasks for smart city initiatives. Home appliances are responsible for a significant share of the energy consumed by buildings. In smart city initiatives, domestic appliances are expected to be intelligent via digital infrastructures [66–69]. According to the 2022 Statista Global Consumer Survey, South Africa, South Korea, China, and India have some of the highest major smart appliance adoption rates globally [70]. In general, large smart appliances are more likely to be owned by households than small ones.

3.2.4. Energy Infrastructure and Facilities

The energy infrastructure is the foundation of the smart city that supplies electric and thermal energies to different interconnected facilities. The energy infrastructure of the smart city should be equipped with smart communication and control infrastructure. It should have the readiness and flexibility to incorporate the increasing energy demand and new distributed energy resources (DER). Therefore, the smart city initiatives emphasize the implementation of smart grid technology that strongly relies on information and communication technologies to achieve better overall system efficiency, facilitate the penetration of DER, and allow new business models and innovative demand-side management. In addition, the smart grid is resistant to internal and external attacks, with a self-healing capacity [71–73]. Furthermore, smart city initiatives consider water and gas utilities as critical infrastructures for smart cities that are often overlooked. Smart infrastructures ensure the efficient and effective management and utilization of water and gas [47,74,75].

Investing in smart grids must more than quadruple by 2030 in order to keep up with the net zero emissions by 2050 scenario, notably in emerging markets and developing nations, despite some progress in recovering from the economic turmoil brought on by the COVID-19 epidemic. For example, as depicted in Figure 5, investment in electricity grids increased significantly by 6% in 2021 as developed economies accelerated spending to support and facilitate the electrification of buildings, industry, and transportation and to make room for variable renewable energy sources on the power grid [76].

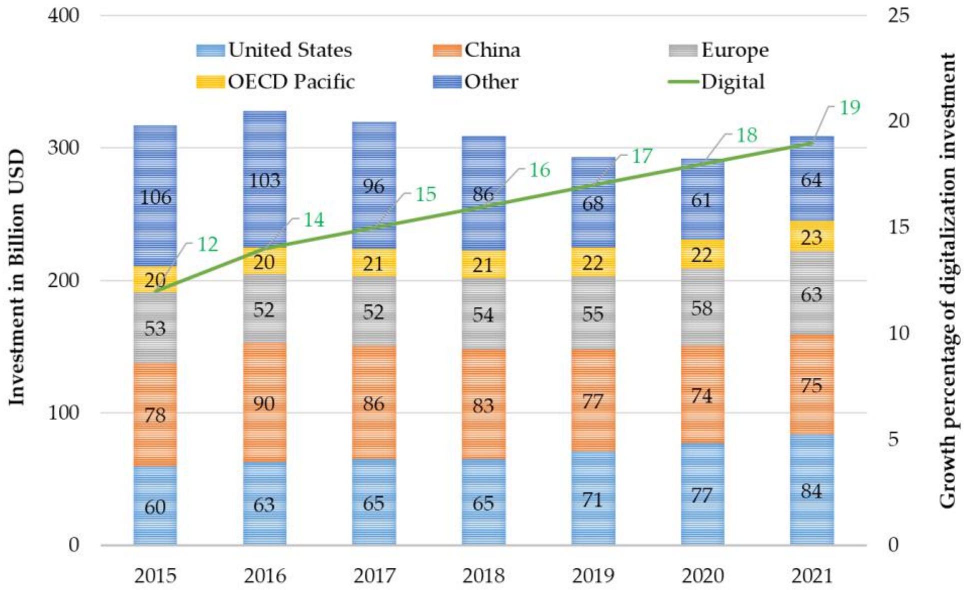

Figure 5. Investment spending on electricity grids, 2015–2021 [76].

3.2.5. Transportation

A smart transportation system makes a difference in how passengers commute, helps municipalities save on expenditures, and provides better services to citizens (ensuring safety and security). Smart transportation systems utilize advanced technologies such as electronic devices, high-speed internet infrastructure, and modern data analytics to provide better information and greater control over traffic flows to the city authorities, ensuring the citizens' comfortable mobility. It is often considered as the first step of the smart city initiative [77]. To reduce GHG emissions and to achieve other benefits, the researchers are putting their efforts forward to popularize alternative transportation systems, such as electric vehicles, by replacing fossil fuel-powered vehicles [78–81]. At the same time, other energy-efficient mass transportation systems, including subways, public buses, and shared taxis, are considered integral parts of the smart city sustainable energy model. In addition to passenger movement, a significant portion of the transportation system (heavy-duty vehicles) is responsible for city freight movement. Therefore, both passenger and freight movement-related transportation systems should be included in modeling the smart city energy system to reduce fuel consumption and improve fuel economy [82–84]. Figure 6 highlights the global electric vehicle market in major cities as of 2019 [50].

3.3. Smart City Energy Models and Tools

Smart city initiatives have adopted different energy modeling and management systems, employing various tools and techniques. In addition to the traditional methods, smart city initiatives utilize AI, IoT, and big data concepts to model energy systems. This section briefly introduces a few of those adopted techniques and tools.

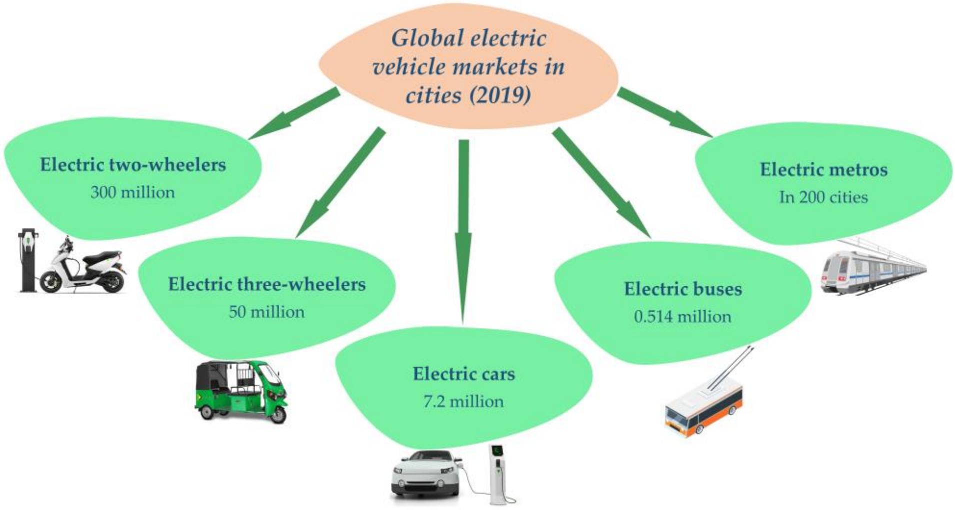

Figure 6. Global electric vehicle markets in cities [50].

3.3.1. Smart City Energy Models

As discussed in the previous section, smart grid infrastructures are the primary enablers of smart city initiatives that incorporate the DER as a combination of both renewable and non-renewable, along with advanced measurement and communication systems, to enhance energy efficiency and to reduce energy losses [85]. Primarily, the smart city initiatives' energy modeling and management systems are based on mathematical optimization techniques. For example, Lin et al. [86] proposed a mathematical model to minimize the energy usage cost of all end-users in one day using peak-load shifting principles, where the peak value was shifted to 1687 kWh from 1768 kWh and the lowest value was improved from 392 kWh to 819 kWh. Hence, the total energy loss was enhanced from 1376 kWh to 868 kWh. In addition, the authors suggested incorporating more renewable energy resources to improve the model efficiency. In [87], the authors studied the potential impact of electric vehicle (EV) interconnections on optimal DER solutions, considering the uncertainty in EV driving schedules. Specialized software, namely the distributed energy resources customer adoption model (DER-CAM), was used to model the optimal DER in microgrids to minimize the total investment costs for the decision makers. The authors also discussed the investment costs of the EV and the minimum payback periods.

Palomar et al. [88] proposed a refinement of cyber–physical component systems based on a cooperative demand response system where the primary objective was to minimize the global energy load. The authors prioritized renewable energy resources over fossil fuel-based resources. Calvillo et al. [89] studied the impact of limiting power flows to the DER. The main objective of the deterministic linear programming model was to minimize the prosumers' (consumer–producer) total energy costs over 20 years. De La Torre et al. [90] presented a mixed-integer linear programming (MILP) formulation to precisely model the price-maker capability of altering market clearing prices for its benefit through the price-quota curve. The day-ahead price quota provided all the information to optimally self schedule, where the primary objective was to maximize the profit of the price maker over the planning horizon. The market clearing price was highly correlated with the served demand. Hamada et al. [91] proposed an approach for securing reserves within a cluster, where the objective was to minimize the costs of electricity and gas consumption.

Bjelic et al. [92] employed the HOMER software for their optimization model to minimize total net present costs on the project lifetime. The authors showed that 97% of GHG reduction could be achieved by integrating renewable energy resources of different types and sizes. Delfino et al. [93] proposed a hierarchical two-level aggregate model to minimize the weighted sum of economic costs, GHG emission costs, and connection losses. Bracco et al. [94] determined the optimal design and operation of the combined heat and power (CHP) distributed generation system by minimizing an objective function that considered both annual costs and GHG emissions. Finally, Marzband et al. [95] illustrated an algorithm to reduce energy costs in the microgrids while meeting the customers' requirements. The proposed algorithm was faster than the non-optimization algorithm and had the potential for real-time application in an extensive system. Furthermore, the proposed approach was cost-effective compared with its counterparts. Table 2 reviews several recently reported energy management and modeling approaches.

Table 2. Smart city energy model review.

Ref.	Modeling Approach	Software Used	Objective	Outcome	Proposals
[86]	Peak load shifting	AIMMS 4.3	Minimization of energy cost	Shifted the peak value	Multi-objectives (operation costs and pollution reduction)
[88]	Cooperative demand response system	Extensible Coordination Tools	Minimization of energy usage	Supported various designs and processes	Introduction of intelligent components with learning capabilities
[89]	Impact of demand response on DER	GAMS	Minimization of prosumers' energy costs	Supported modeling under thermal constraints	Simplification of the planning and operation of the DER
[90]	Optimization	GAMS	Profit maximization of the price maker	Ensured optimal profit for the price maker	No proposal
[91]	Securing reserve within a cluster	MILP	Minimization of electricity and gas costs	Performed well with PV penetration	Consideration of the retail price and optimal operation relationship
[92]	Optimization	HOMER	Minimization of the net present costs	Minimized and levelized costs for energy on the project horizon	Financial incentives for the increased use of renewable energy sources
[87]	Incorporation of uncertainty	DERCAM and GAMS 23.0.2	Minimization of total investment costs	Minimal impact of driving uncertainty	Consideration of EV adoption as the DER
[93]	Two-level aggregate model	DigSilent, MATLAB, and Lingo 9.0	Minimization of economic costs and reduction of GHG emission	Multilevel and centralized approach	Comparison between the proposed architecture and other possible architectures
[94]	Optimization	GAMS	Minimization of costs (annual and GHG emission)	Adoption of DER ensured better economic savings and GHG emission reduction	Consideration of technical and economic constraints
[95]	Demand response	GAMS and Power Emulators	Minimization of energy costs	Confirmed demand response with minimal costs	No proposal

3.3.2. Smart City Energy Modeling Software

This section reviews different computer-aided design tools that can be employed to model effective energy management systems for smart city initiatives. All tools have pros and cons; hence, finding a versatile tool that addresses every aspect of smart city energy modeling is challenging. However, the ideal energy tools depend highly on the specific objectives that must be fulfilled [96]. Among many tools, the DER-CAM is a powerful and comprehensive techno-economic decision support tool conceived at the Lawrence Berkeley National Laboratory in the United States of America (USA). It outputs distributed generation technologies' lowest cost or GHG emission layout for specific buildings. It focuses on analytics, planning, and operations of distributed energy resource systems. Using a paid version of the software, it is possible to optimize microgrid layouts and define specific microgrid frameworks whenever necessary [97].

Another well-known and popular software, HOMER, supports the design and optimization of microgrid systems by evaluating the systems' lifecycle costs based on different configurations and parameters. This software allows the modeler to create a complete microgrid framework. It can simulate several devices that generate, absorb, and transform electricity, heat, and hydrogen. These devices include boilers, PV modules, wind turbines, electrical converters, electrolyzers, batteries, and hydrogen tanks [98]. Other popular software include: advanced interactive multidimensional modeling system (AIMMS); BALMOREL; BCHP; electricity market complex adaptive system (EMCAS); general algebraic modeling system (GAMS); EnergyPLAN; long-range energy alternatives planning (LEAP); programme-package for emission reduction strategies in energy use and supply (PERSEUS); RETScreen. Table 3 briefly discusses the capabilities and limitations of the most popular energy modeling software.

Table 3. Relevant energy modeling software.

Software	Developer	Capabilities	Limitations
AIMMS [99]	AIMMS, Netherlands	A robust and versatile tool for energy management that effectively analyzes network conditions and suggests enhanced local or grid-wide dispatch instructions	A few advanced features may not be interactive to the end-users
BALMOREL [100]	Open Source, Denmark	A partial equilibrium tool that emphasizes the electricity sector and combined heat and power considering costs and GHG emissions	Transport technologies are not represented as standard
BCHP Screening Tool [96]	Oak Ridge National Laboratory, USA	An assessment tool for evaluating potential savings of the combined cooling, heating, and power systems for buildings	Cannot deal with large electric networks, heat, or transport sectors
EMCAS [96]	Argonne National Laboratory, USA	An operational and economic impact assessment tool under various external events	Does not support operational optimization feature
EnergyPLAN [101]	Aalborg University, Denmark	National or regional energy planning tool	Does not optimize system investments
DER-CAM [97]	Lawrence Berkeley National Laboratory, USA	An energy flow optimization tool for cost minimization	Does not have any built-in in situ stochastic programming
GAMS [102]	GAMS Development Corporation, USA	A tool for formulating basic building blocks of optimization models	Simulation of smart city energy modeling might not suffice
HOMER [98]	National Renewable Energy Laboratory, USA	A tool for simulation and optimization of stand-alone and grid-connected electric networks	Simulation capability is limited to microgrid systems only
LEAP [96]	Stockholm Environment Institute, Sweden	A tool for national energy system analysis and for tracking energy consumption, production, and resource extraction	Does not support operation and investment optimization
PERSEUS [96]	Universität Karlsruhe, Germany	A multi-period linear programming technique to analyze energy and material flow considering all possible costs within the system	Does not support the operation optimization feature
RETScreen [103]	Natural Resources Canada, Canada	A clean energy management system for energy performance and renewable energy project-feasibility analysis	Does not support advanced calculations and cannot save, print, or export files in the free view mode version

3.3.3. Latest Trends of Energy Modeling Employing AI, IoT, and Big Data

Artificial intelligence, the internet of things, blockchain, and big data are the broad concepts that could potentially contribute to improving or complementing smart city energy modeling. The techniques are based on linear or nonlinear differential and integral equations and have successfully solved different engineering problems [104–110]. The neural network, a subset of AI, does not require a prior mathematical model that adjusts its weights and biases by employing an appropriate learning algorithm [111]. It is an adaptive system and can treat complex and nonlinear problems. In a nutshell, the neural network provides an analytical alternative to conventional techniques often limited by strict assumptions [112]. Another member of the AI family is the adaptive multi-agent system that deals with real-world complex systems by generating real-time models, respecting generalization properties, openness, and scalability [113]. Conceptually, AI is linked with the internet of things and big data. These three concepts are interconnected and integrating these concepts into smart city initiatives can bring numerous successes. The term big data generally refers to large and complex data sets that represent digital traces of human activities and may be defined in terms of scale or volume, analysis methods, or effect on organizations. For instance, the Seoul government identified the patterns and demands of the usage of the city bus at midnight and subsequently improved midnight public bus services by analyzing the big data. Attempts to predict forest fires from the synoptic patterns using a machine learning model in Canada could be extremely helpful in developing a more innovative ecosystem for smart cities [114]. However, big data has challenges, including data quality management, data integration from different sources, data privacy, understanding users' needs, enhancement of geographic information delivery methods, and service-oriented perspectives [115].

Conversely, the IoT combines embedded technologies, including wired and wireless communications, sensor and actuator devices, and physical objects connected to the internet. Systems should be able to access raw data from different resources over the network and analyze this information in order to extract knowledge [116]. With internet-connected sensory devices, the IoT can be assumed to be analogous with human senses [117]. The IoT concepts can be applied across all aspects of smart cities, including intelligent energy, smart mobility for smart citizens, and urban planning. It could be considered a vital tool for forecasting future energy consumption in smart cities [116]. Table 4 presents a few representative case studies to illustrate the importance and great potential of the interconnected concepts of AI, IoT, and big data in various aspects of smart city implementation, emphasizing the smart city energy management system.

Table 4. Application of AI, IoT, and big data in the smart city.

Ref.	Application	Approach	Results
[118]	Forecasting of solar PV resource availability	Multilayer perceptron and Elman neural networks	The Elman neural network with a big data window and less complexity showed superior performance over the multilayer perceptron neural network
[113]	Development of an innovative campus	AMOEBA, a multi-agent self-adaptive system	The model performed in real time and adapted the agents' behaviors by mapping the context and output
[119]	Predicting city traffic	Different traffic prediction techniques	Non-parametric predictive techniques performed better due to their ability to deal with linear or nonlinear, stationary or non-stationary, and static or dynamic processes
[120]	Home energy management system	Neural network-based Q-learning algorithm	The self-learning approach offered competitive solutions even during the peak period
[121]	Smart grid fault diagnosis	Machine learning approach	Detected, classified, and located faults with reasonable accuracy
[122]	Urban building energy simulation	Combination of the data-driven machine-learning technique	Ensured accurate and robust results that provided valuable insight into early-stage building design, building conservation, and policymaking.
[123]	Travel-to-school mode choice	Various AI techniques	Selected the mode choice of the students, either passenger cars or walking, to reduce energy consumption
[124]	Forecasting district energy demand	A set of artificial neural networks	Predicted the peak demand successfully for flexible and effective management of district energy systems

Table 4. *Cont.*

Ref.	Application	Approach	Results
[125]	Unified framework for optimization and scheduling	IoT-based optimization technique	Demonstrated results justifying the deployment of IoT-based solutions for energy-efficient scheduling optimization
[126]	Healthcare operation improvement	Machine learning approach	Improved human ability to manage healthcare operations and save energy
[127]	Predicting mobility service	Structural equation modeling, neural approach	Suggested the growth potential of IoT-based services and transforming the present system to an intelligent one
[128]	Microgrid energy management	Blockchain	Increased profitability and consumer satisfaction while reducing the environmental impacts
[129]	Dynamic energy pricing	Blockchain and smart contracts	Offer dynamic pricing of energy based on supply and demand by upholding privacy, anonymity, and confidentiality

4. Smart City Energy Modeling Challenges and Prospects in Southeast Asia

This section presents the challenges in smart city energy modeling and prospects considering the energy outlook and policies of Southeast Asia countries.

4.1. Smart City Implementation Challenges

Based on the experiences of the established smart cities, Southeast Asian countries also aspire to implement smart city concepts in the region to provide a better livelihood for their citizens. A good number of initiatives are presented in Table 5, as adopted from Ref. [46]. The cities in the region can take advantage of the smart solutions due to their improved energy infrastructure, digital literacy, and smartphone penetration. The available financial constraints of the cities can be overcome through the involvement of the private sector, independent finance institutions, and donor agencies. The McKinsey Global Institute (MGI) reported that implementing smart city concepts can deliver a real quality of life to the region's people. It could annually reduce up to 270,000 kilotons of GHG emissions, save USD 16 billion in energy bills, create 1.5 million jobs, avert up to 5000 unnatural deaths, reduce 12 million disability-adjusted life years, and save 8 million person-years' computing time in the region [130].

Table 5. Ongoing and planned smart cities in Southeast Asia [46].

Country	City
Singapore	Singapore
Malaysia	Kuching, Kota Kinabalu, Kuala Lumpur, Johor Bahru
Indonesia	Makassar, Jakarta, Banyuwangi
Thailand	Phuket, Chon Buri, Bangkok
Philippines	Manila, Davao City, Cebu City
Vietnam	Ho Chi Minh City, Hanoi, Da Nang
Myanmar	Yangon, Mandalay, Naypyidaw
Laos	Vientiane, Luang Prabang
Brunei	Bandar Seri Begawan
Cambodia	Krong Siem Reap, Phnom Penh, Krong Battambang

There are many challenges to implementing smart city concepts in Southeast Asia, including the lack of smart visionary leadership and governance, support from the citizens, lack of investment, and sustainable and strategic model development. Other challenges are understanding the technological aspects, the heterogeneity of smart devices, private and public regulatory bodies, and overall awareness of optimal management and modeling of the available resources [22–25]. The Asian Development Bank has estimated that the region would soon require enormous investments across four sectors (power, transportation, water and sanitation, and telecommunications) to implement smart city initiatives. It is expected that many countries cannot afford the initiatives that require massive investments without capital and expertise injections from the private sector [13]. However, a few countries, such as Singapore and Malaysia, can afford the required investments to implement smart city initiatives. In addition to the investment issue, the lack of appropriate leadership and governance arrangements appear to constitute the most severe challenges for most cities' effective transformation [131–133]. Without the proper administration and appropriate governance system, even the best technology and colossal investment cannot guarantee the successful implementation of smart city concepts in the region [13]. As evident from Nakhon Nayok, Phuket, and Chaing Mai provinces of Thailand, where lack of coherent and transparent policy, myopic insight, and lack of framework on the part of both the central bureaucrats and provincial staff resulted in partial complete failure of the project [134,135]. Furthermore, Southeast Asian countries' smart city initiatives are narrowly focused and have lower impacts than western countries [136]. Although the cities in the region do not need to replicate the global generic template, they can forge their models to reflect their priorities and challenges [130]. However, at the same time, these initiatives should not overlook or avoid any essential aspects of the generic template.

Additionally, the citizens of smart cities should play a very active role in interpreting the data in order to tackle anticipated and existing challenges to build a more sustainable city [137]. If the citizens are not supportive and are unaware of technological aspects, the smart city initiatives will face considerable difficulties during the transformation. Furthermore, improper and inappropriate strategic planning and modeling can also introduce uncertainties over implementing smart city concepts [138]. According to 80 percent of survey takers in Bandung and Jakarta, Indonesia, the lack of information for city inhabitants in most cities is considered a significant challenge for implementing smart city initiatives. Therefore, it is vital to present information to the city inhabitants easily and understandably rather than in a technical and abstract manner [12]. While many citizens complain about the proper way of information delivery, many experts are anxious about the cyber security issues of the smart cities that heavily rely on digital infrastructure and connecting everything to the internet. Considering the mentioned notes, Cyber Security Malaysia (CSM) is building an internet of things security framework to champion the smart city initiative of Cyberjaya. At the same time, Singapore has already made a government cloud to securely host information and data at the central facility [12]. Moreover, requisite staff knowledge is equally important, as the whole project will fail without effective communication among the workforce. Hence, apart from allocating budgets and resources, a change in the bureaucratic culture is equally vital for executing a smart city project [139].

Transportation or mobility is another challenge for Southeast Asian countries facing smart city initiatives. In large cities such as Jakarta, traffic congestion is a major issue that negatively affects the productivity and overall living quality of the citizens [140]. In response, introducing an intelligent transportation system can reduce the number of vehicles on the road, save energy consumption, and upgrade livelihood standards [141]. Moreover, a massive adoption of electric cars would undoubtedly lead to a considerable reduction in GHG emissions and an improvement in load profile and load factor [142]. In addition, the city inhabitants can make money by adequately utilizing electric vehicles, sending energy back to the grid during the peak load time, and charging them during the off-peak time [143]. Another dominant feature of smart city initiatives is the optimal allocation and management of the available resources. For example, Hajari and Karimi [144] proposed a large-scale resource allocation technique that provided the optimal locations within a reasonable response time by excluding the ineligible sites and maximizing the spatial coverage.

Moreover, significant endeavors and attention need to be dedicated to the appropriate modeling and management of the energy demand and resources for the perfect implementation of smart city initiatives, as it is considered as one of the most challenging issues. In response to the issue, Calvillo et al. [25] proposed an advanced and improved energy model in the smart city context, along with a few necessary and essential recommendations. Their recommendations include: (i) identification, study, and finding of the implicit relationship of the energy elements; (ii) detailed modeling and simulation for improvement of the existing and planned energy systems; (iii) adoption of distributed generation systems along with proper control and demand response schemes (microgrid and smart grid paradigms in the long run); (iv) adoption of EV in the transportation sector. Therefore, smart city initiatives can adopt the mentioned recommendations to address their challenges related to energy management and modeling.

4.2. Smart City Energy Modeling Challenges

The energy model components of the smart city are demonstrated in Figure 2. In the smart city, the primary energy generation units are the power plants owned by the utility companies and independent power producers (solar, biomass, wind turbines, etc.). The operation and control centers of the countries determine the amount of electricity to be supplied to the end-users at a certain time, whether to produce electricity from fossil fuel or renewable resources. They manage their operation based on the electricity consumption data of the end-users by following the predetermined energy modeling algorithms and hierarchy. At the upper hierarchy level, the primary objective is to minimize the total investment costs, whereas the secondary aim is to reduce GHG emissions. At the lower level, the modeling focuses on minimizing the daily energy costs of end-users. However, the energy modeling of smart city initiatives is not straightforward and experiences a wide range of challenges, as reported in [145–153]. In Southeast Asian countries, the coordination amongst various energy producers is one of the significant challenges that considers the inclusion of renewable energy resources in the energy mix. Other than minimizing the energy cost, GHG emission reduction should also be considered during decision making. Therefore, a win–win solution needs to be drafted that considers the interests of the energy producers while modeling the energy supply chain for smart cities. Additionally, the detrimental impacts of a massive integration of EVs into the energy system need to be analyzed carefully. Possible impacts could be increased peak-load demand, reduced reserve margins, voltage instability, and reliability problems [147].

The proper collaboration between different smart city components, including the citizens, administrators, and city devices, is a must for successfully implementing a smart city energy management system [149]. Hence, articulating concise and concrete energy policies by the decision makers, architects, developers, and implementers can enhance the implementation of smart city initiatives and appropriate energy management systems that reduce energy consumption and GHG emissions [150]. Therefore, developing a sustainable energy management framework by engaging energy consumers by providing innovative incentive schemes can also be considered as one of the prominent challenges [151]. In addition, finding a trade-off between the living standards of smart city residents and efficient energy policies to reduce overall energy consumption is another challenge for policymakers [152].

Most reported energy management systems consider moderate climates with seasonal variations, for instance, European and North American climactic conditions. Therefore, such an energy management scheme cannot be implemented immediately in Southeast Asian countries due to different climatic conditions. The climatic conditions of tropical countries with high stable temperatures and humidity and the lack of seasonality should be considered while developing their energy models [153]. Moreover, renewable energy resource generation and load demand are intermittent; hence, this issue must be considered while developing robust energy models [154–157].

The necessity of energy-efficient transport systems is inevitable. Fast, efficient, and clean mobility inside cities is one of the main challenges commonly addressed by local governments due to large energy requirements and significant impacts on air pollution [158]. Still, transport systems must be made more efficient, even in developed countries. Additionally, the development and implementation of smart water and wastewater management systems to replace traditional and less efficient methods may significantly reduce the consumption of energy and maintenance time [159]. Hence, developing an energy management system requires further exploration and investigation. Another challenging issue for smart city energy modeling is the development of efficient and smart heating and cooling systems based on numerical and computational techniques for city buildings, considering associated uncertainties [160]. Finally, finding innovative ways to monitor and control energy consumption to deal with the surging growth of demand and raising energy costs can be considered another challenging task.

In response to the mentioned challenges, appropriate policy development, innovative technological solutions, and upgradation of the status quo are necessary. For instance, AI, IoT, blockchain, cloud computing, and big data can be utilized to develop intelligent energy management systems as they offer promising solutions and valuable insights into the problems [161–163]. However, the transformation of traditional management systems to data-driven intelligent systems poses challenges due to the lack of a skilled workforce. Furthermore, the data quality, integration, privacy, understanding, delivery, and design of services might introduce further challenges [115]. Therefore, the appropriate processing of the gathered data, platform compatibility, and workforce readiness is necessary to implement intelligent energy management systems effectively. Furthermore, the lack of appropriate policies in a few countries for renewable energy integration can also be considered as an obstacle [164].

4.3. Energy Outlook and Policies

Southeast Asian countries are eager to increase their share of renewable energy and have taken several initiatives to reduce their dependence on fossil fuels for energy requirements. As a result, various policies have been adopted to make renewable energy more lucrative. For instance, a feed-in tariff (FiT) is an energy supply policy that supports the development of new renewable energy projects by offering long-term purchase agreements to sell renewable energy-based electricity. The policymakers designed the FiT in two ways: fixed price and premium policies. The fixed-price policy provides a guaranteed payment for a predetermined period, usually independent of the market price. On the other hand, the premium policy offers a premium on top of the spot market electricity price and the payment level is directly tied to the electricity market price. Therefore, it rewards renewable energy infrastructure developers when market prices are high and penalizes them when the prices drop [165]. In addition, other prominent policies for the grid integration of renewable energy resources are net metering and net billing schemes. The first scheme compensates the prosumers at the retail rate, whereas the second compensates at the lesser supply or wholesale rate [166]. Brief comments on the renewable energy plan and policies adopted by some Southeast Asian countries to increase sustainable generation in their energy mixes are discussed in the subsequent section.

4.3.1. Indonesia

The domestic energy consumption of Indonesia is expected to grow by three times from 2010 to 2030. The government adopted a national energy policy in 2006 to establish the laws, regulations, targets, and actions to be implemented in line with future energy demands [167]. As of 2021, 10.39% of the primary energy consumption comes from renewable energy resources [168]. However, the country set targets to increase renewable energy shares to 23 and 31% of the energy mix by 2023 and 2050, respectively [169]. In addition, the country implemented the FiT mechanism for the utility-scale and net metering schemes for rooftop solar PV systems. The government has revised the schemes several times to support the growth of renewable shares in the energy mix [170–172].

4.3.2. Malaysia

In 2021, Malaysia consumed 8.06% of its primary energy from renewables [168]. The country planned to increase its renewable energy share to 31 and 40% of the national installed capacity by 2025 and 2035, respectively [173,174]. FiT and net energy metering schemes have been implemented to attract citizens and business enterprises to achieve the renewable energy growth plan by optimizing socio-economic benefits [175–177].

4.3.3. Singapore

Singapore is one of the countries that utilizes the least number of renewables. As of 2020, only 0.31% of the country's primary energy consumption comes from renewable sources, far below the world's average (~13.46%) [168]. However, the government has updated its renewable energy targets and would like to achieve 2 GW installation capacity by 2030 and has already reached its 2020 target of 350 MW [178]. Furthermore, the country awarded various research grants to research institutes and universities to drive the country towards the national sustainable development goal [179,180]. In addition, the government introduced several schemes, including metering credit, renewable energy certificates, and solar financial incentive schemes to attract citizens and business owners toward the installation of renewable energy [181].

4.3.4. Thailand

The country produced 7.11% of the primary energy requirement from renewable resources as of 2021 [168]. In 2016, the country introduced the Thailand integrated energy blueprint (TIEB) as a long-term plan to enhance energy development, security, and connectivity. The 20-year plan focuses on reducing the dependence on imported natural gas by increasing the share of the energy mix via clean coal and renewable energy. The program aims to reduce the energy intensity by 30% and to increase the renewable energy share to 30% of the total energy consumption by 2036 [182]. In addition, similar to other countries, Thailand introduced and revised several renewable energy policies, including the FiT and net metering [183–185].

4.3.5. Vietnam

Vietnam is one of the leading renewable-energy producer countries that generated 22.73% of the primary energy consumption from renewable resources in 2021 [168]. It aims to develop 50% of the energy consumption by 2045 from solar and wind generation systems that would require an installed capacity of 42.7 GW of onshore wind capacity, 54 GW of offshore wind, and 54.8 GW of solar capacity [186]. However, the country has already emerged as the leader in renewable energy adoption in Southeast Asian countries and reached 42.7 GW of renewable generation capacity (approximately 56% of total generation capacity) in 2021. It implemented various attractive policies, including the FiT and gross metering, to enable the renewable energy plan [187–189].

4.3.6. Philippines

The country generated 10.90% of its primary energy consumption from renewable resources in 2021 [168]. The government has already achieved 7.65 GW of renewable energy generation capacity and plans to add 73.87 GW of additional capacity by 2040 to reach 50% of the country's power generation mix [190]. The government implemented FiT and net metering schemes to increase renewable energy generation capacity in the country [191,192].

4.3.7. Other Countries

As of 2021, Cambodia, Myanmar, and Laos installed 1.8 GW (57% of total capacity), 3.44 GW (45% of total capacity), and 8.49 GW (~82% of total capacity) of renewable energy generation capacity, respectively, whereas the renewable energy generation capacity in Brunei is only 1 MW [187,193]. As per the plans, Brunei will generate 30% of the electricity from renewables by 2035 [194], Cambodia will increase its renewable energy generation capacity to 65% of total capacity by 2030 [195], and Laos will produce 30% of the total energy consumptions by 2025 from the renewables [196]. Myanmar will increase its renewable energy capacity from between 9.1 GW and 14.5 GW by 2030 [197]. Like others, most countries have adopted different renewable energy policies, including FiT and net metering [198–200].

In addition to renewable energy targets and the implementation of different policies, the Southeast Asian countries also plan to promote energy efficiency, phase down/out fossil fuel-based generation, reduce GHG intensity, and increase electrification of various sectors to achieve net zero emissions either by 2050 or 2060 [194]. Therefore, such clean energy and effective energy management plans are expected to expedite the smart city initiatives in Southeast Asian countries. Furthermore, the mentioned energy policies will enhance energy security and reduce the reliance of city dwellers on traditional energy distribution strategies. Thus, the nations will have more resilient energy infrastructures and will gain needed economic prosperity through the targeted smart cities that will enhance the citizens' quality of life.

5. A Futuristic Approach to Smart City

Smart cities are thought of as investments that employ technological advancements as tools to promote and enhance living standards. Data are at the forefront when developing and putting into practice the idea of smart cities. Through adequate training and awareness campaigns, it is possible to ensure that the residents of a smart city are fully aware of its uses and adhere to the best practices for privacy, safety, and security [201]. The government is responsible for developing data policies; thus, it must be well-coordinated with data and have appropriate documentation and codebooks [202]. Building information and communication technology-based smart infrastructure, integrating smart infrastructure into applications to gather and analyze data to optimize operations, and exploring new opportunities in terms of current developments and their impact, issues, and future requirements are just a few of the stages that need to be covered on the roadmap. There will be instances throughout the automation process and the construction of a smart city where robotic systems will take greater control while keeping an eye on the inhabitants. We need to have a realistic perspective on technology that considers societal ideals such as transparency and personal, social, economic, digital, and professional growth. A human touch will be crucial in this complicated array of functions, expectations, data, and discovering insights.

A super-smart society is intended by Industry 5.0, also known as Society 5.0, which is seen as a progression of earlier industrial revolutions (Figure 7). The smart cities under Society 5.0 will create plans and regulations regarding IoT systems, a dedication to research and development at different levels, and attention to educational reforms, including technological literacy. In addition, Society 5.0 will encourage diverse, adaptable, and dynamic working circumstances that will emerge a new category of occupations [203–208].

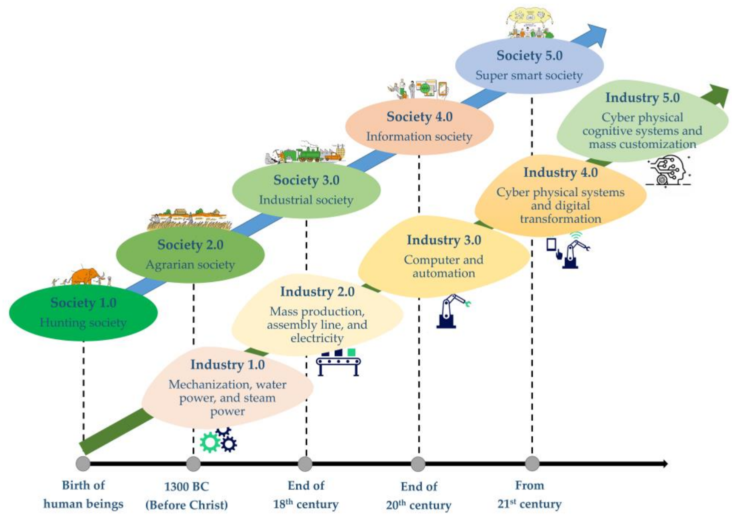

Figure 7. Timeline of industrial and societal transformations [203–208].

6. Conclusions

Developing an efficient and clean energy management system is one of the most challenging tasks of smart city initiatives. This paper identified smart-city initiatives in Southeast Asian countries, focusing on energy systems. It investigated the status of smart systems in energy generation and storage, infrastructure, and model development. It identified the unique challenges of these countries in implementing smart energy systems. It critically reviews many available energy modeling approaches and addresses their limitations and strengths, focusing on the region. Typically, it was observed that the upper-level objective of smart city energy modeling is to minimize investment costs and GHG emissions by deploying renewable energy resources based on distributed energy resources. This paper also provided a preliminary framework for a successful energy system that exploits AI, IoT, blockchain, and big data.

Trends indicated that smart systems are becoming increasingly prevalent in energy generation and storage, infrastructure, and modeling. All the countries of this region have been moving towards renewable energy sources and emphasizing energy efficiency with specific targets. As a result, smart system policy development has been progressing. However, effective resource management and modeling and the provision of strong leadership and governance are significant obstacles in these nations. The energy management and modeling system in this region will likely benefit from the most recent discoveries and applications of artificial intelligence (AI), the internet of things (IoT), and big data. According to what we learned by comparing different energy models, selecting suitable models is crucial for an intelligent energy system to work efficiently. Furthermore, before the development of any model, feasibility studies of microgrids, the integration of renewable energy resources considering associated uncertainties, the climatic condition of the targeted region, and the application of artificial intelligence in modeling must be conducted. Finally, this paper demonstrated present and upcoming challenges pertaining to smart city energy modeling that can be considered as potential research opportunities in this field.

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