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ARTICLE

Assessing APEC's Role in Urban Energy Transitions and the Environmental Impact: A Comparative Analysis of China, Japan, and Singapore

Wendkuuni Steve-Harold Kaghembega [1,2*] ***, Zhu Li*** [1,2]***, Pengfei Xie*** [1,2]***, Yujiao Huo*** [1,2]

[1] *Department of National Energy Storage Technology Industry-Education Integration Innovation, Tianjin University, Tianjin 300072, China*

[2] *APEC Sustainable Energy Center, Tianjin University, Tianjin 300072, China*

ABSTRACT

This study evaluates the role of the Asia-Pacific Economic Cooperation (APEC) in shaping urban energy transitions through a comparative analysis of China, Japan, and Singapore. Although regional cooperation has become an important complement to global climate governance, empirical evidence of APEC's substantive influence on urban decarbonization remains limited. The research integrates qualitative institutional analysis with quantitative assessment using a panel dataset and the Shared Socioeconomic Pathways framework, employing Shared Socioeconomic Pathway 5 (SSP5) to examine environmental trajectories under fossil-fuel-intensive growth conditions. The findings show that APEC operates primarily through soft governance mechanisms policy coordination, knowledge diffusion, and technical cooperation rather than binding regulatory instruments. Its influence appears in the strategic alignment of national and municipal energy policies with regional low-carbon frameworks, though implementation pathways diverge according to domestic institutional configurations. China adopts a centralized, state-led model of clean energy urbanization; Japan advances technologically driven smart energy systems within a decentralized governance structure; and Singapore applies an integrated, data-driven sustainability framework emphasizing regulatory coherence and performance benchmarking. Scenario results under SSP5 reveal persistent structural coupling between economic growth and carbon emissions across all three economies. China's

*CORRESPONDING AUTHOR:

Wendkuuni Steve-Harold Kaghembega, Department of National Energy Storage Technology Industry-Education Integration Innovation , Tianjin University, Tianjin 300072, China; APEC Sustainable Energy Center, Tianjin University, Tianjin 300072, China; Email: ksteveharold@gmail.com

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economic scale generates substantial emissions from coal- and oil-intensive sectors, while Japan's continued reliance on fossil fuels and liquefied natural gas constrains deeper decoupling despite lower energy intensity and Singapore's CO_2 emissions, strong dependence on imported fossil fuels, making its carbon footprint largely embedded in regional supply chains.

Keywords: APEC; Clean Energy; Low Carbon Model Town; Sustainable Development Goal (SDG)

1. Introduction

The Asia-Pacific Economic Cooperation (APEC) was established in 1989 to promote regional economic cooperation in the Asia-Pacific region. By encouraging balanced, inclusive, sustainable, innovative, and secure growth and accelerating regional integration, the 21 APEC member economies aim to create greater prosperity for the people of the region [1]. However, APEC economies are also committed to preserving and improving environmental quality and to sustainability. The protection of natural resources and the sustainability of development are key issues for APEC economies [2]. Despite the challenges, APEC economies are determined to address them by implementing policy reforms, strengthening cooperation, and promoting clean technologies and green innovations. The Asia-Pacific (APEC) region accounts for the largest share of global greenhouse gas emissions and roughly half of the world's energy demand. This means that the success of Asia-Pacific (APEC) countries, including China and India, in transitioning to clean energy sources is crucial for meeting global emission targets [3]. To achieve the Paris Agreement goals, it is essential that large economies strengthen their efforts to reduce carbon emissions. APEC plays a crucial role in shaping the energy transition in urban environments by providing a platform for collaboration, policy guidance, and capacity building among member economies [4]. APEC focuses on promoting low-carbon energy, renewable energy, and sustainable urban development through various initiatives, including policy dialogues, workshops, and technical assistance programmes.

The energy transition is essential not only to achieve the goals of Sustainable Development Goal 7 (SDG 7) [5], but also to provide spillover benefits to many other SDGs through affordable, reliable, sustainable, and modern energy for all. In addition, fulfilling the commitments made under the Paris Agreement requires a rapid energy transition in the Asia-Pacific region. The energy transition can contribute to energy security, reduce energy poverty, deliver a wide range of social benefits, and significantly lower environmental and health risks [6]. To achieve this, the energy transition must address both supply and demand. On the supply side, it involves affordable, reliable, and secure access to electricity and clean fuels and technologies, as well as a shift towards more sustainable and environmentally friendly energy resources, technologies, and infrastructure [7]. On the demand side, it requires significant improvements in energy efficiency across the economy. From a public policy perspective, the transition requires government programmes and tax policies to align with the SDGs and national commitments to reduce greenhouse gas emissions under the Paris Agreement. A timely energy transition also depends on strong government leadership, robust public engagement, mobilisation of market forces, and supportive public policy. Social and environmental benefits and costs not yet reflected in energy markets need to be incorporated into market prices so that consumers and government officials can make informed energy decisions [8].

The 21 APEC member economies in the Asia-Pacific region account for almost 46% of the world's population and produce more than 58% of its economic output. Most of this production occurs in cities, especially large ones. With more free trade agreements being signed between APEC member economies, the prospects for the region and its cities appear bright [9]. However, urban development in the region has largely been unsustainable. Many cities face major challenges related to urbanization, the environment, human capital, governance, and inadequate infrastructure. Income inequality is increasing, and unemployment is rising [9]. These issues pose a significant threat to the future sustainability, prosperity, and livelihoods of people living and working in the region's cities.

The main objective of this paper is to examine how APEC shapes urban energy transitions and assess the environmental impacts. This study combines energy transition and green innovation, which have emerged as new hopes for addressing the environmental impacts of human activity, including biodiversity loss and increased environmental degradation. Therefore, developed and emerging economies are focusing on green innovation and energy transition to tackle the environmental impact. To achieve these objectives, the research is divided into several main sections. It begins with an introduction that sets the context of APEC's environmental and energy commitments. The second section provides a literature review summarizing existing research on the urban energy transition and APEC sustainability frameworks. The third section outlines the methodology, including a qualitative policy analysis and case study approach. The fourth section presents the core analysis by assessing APEC's energy-related initiatives and providing case studies from selected economies and the environmental impact. The fifth section discusses the implications of the findings and the role of regional cooperation in promoting urban energy reform. The research concludes with policy recommendations and final reflections on APEC's strategic direction in promoting a sustainable urban energy future.

2. Literature Review

2.1. Overview of Global Energy Transition Trends in Urban Environments

Urban environments are increasingly recognized as critical arenas for the global energy transition, as cities consume more than two-thirds of the world's energy and are responsible for around 70% of global CO_2 emissions [10]. With increasing urbanization, especially in Asia, Africa and Latin America, cities are under growing pressure to adopt sustainable and resilient energy systems. The global trend is towards integrating renewable energy sources, improving energy efficiency, electrifying heating and transport systems, and introducing smart energy management technologies. Solutions based on renewable energies such as photovoltaics (PV), solar thermal energy, district heating with biomass or geothermal energy, and building-integrated energy systems are increasingly being used in urban planning [11]. In addition, the electrification of end users, especially heating, cooling and mobility, in conjunction with decarbonized electricity grids, is central to urban net-zero strategies [12]. Energy efficiency improvements through green building standards, retrofitting, and digital energy optimization are also being strongly promoted.

Cities in Europe, North America and parts of the Asia-Pacific region have taken the lead in implementing ambitious low-carbon urban strategies [13]. The European Union (EU)'s "100 climate-neutral cities by 2030" initiative and China's pilot programmes for low-carbon cities are examples of regional strategies to promote sustainable urban transformation [14]. Nevertheless, challenges remain, especially in developing countries. These include a lack of funding, outdated infrastructure, political fragmentation, and insufficient local capacity [15]. Global cooperation platforms such as C40 Cities, the Global Covenant of Mayors, and regional groups such as APEC are becoming increasingly important to harmonise policy efforts, share best practices, and accelerate progress towards a sustainable, low-emission urban environment [16]. Environment and greenhouse gas emissions affect environmental quality and climate change, and these emissions are minimized with clean energy sources. It has been found that renewable energy generation, together with financial development, significantly improves environmental quality in APEC economies [17]. In contrast, the intensification of technological innovation, economic expansion, and population growth has the opposite effect. Furthermore, a bidirectional causal relationship exists between the environmental footprint and renewable energy consumption, economic growth, and technological innovation. Daszkiewicz [18] found a negative correlation between the energy transition (primarily the increase in the share of renewable energy) and CO_2 emissions. This conclusion is supported by many other studies from different regions of the world.

Renewable energy policy can be subdivided into target setting and strategic planning (energy strategies, action plans, and targets), measures to cover investment costs (subsidies, rebates, soft loans, tax incentives, tax exemptions, etc.), energy production measures (feed-in tariffs, feed-in premiums, auctions, tenders, etc.), and regulatory instruments (standards, labelling, etc.) [19]. However, not all of these instruments are fully applicable to power generation or heating and cooling. According to Onifade et al. [19], the most important instruments are those in the "target setting and strategic planning" group, feed-in tariffs and feed-in premiums, and fiscal instruments. Equally relevant for all sectors are supporting policy instruments, including education and training, information dissemination, and research and development.

2.2. APEC-Specific Trends and Initiatives Supporting Urban Energy Transition

Within the Asia-Pacific region, APEC plays a central role in promoting the energy transition in urban environments through policy coordination, technical cooperation, and knowledge sharing [20]. As APEC includes both developed and developing economies, it faces a range of challenges and opportunities in urban energy. Recognizing the urgency of climate action and sustainable development, APEC economies have jointly committed to reducing greenhouse gas emissions, increasing energy efficiency, and accelerating the deployment of renewable energy technologies, especially in densely populated urban areas [20]. Several APEC flagship initiatives directly support the urban energy transition. The APEC Energy Working Group (EWG) [21] leads efforts to promote clean energy and energy efficiency, with a particular focus on urban infrastructure. The Energy Smart Communities Initiative (ESCI), launched in 2010, encourages member economies to collaborate on smart urban energy solutions, including the integration of renewable energy, green buildings, and smart grids [22]. Similarly, the Low Carbon Model Town (LCMT) project provides technical and policy guidance to help cities develop comprehensive low-carbon plans and serves as a replicable model for other urban centres in the region [23]. APEC also focuses on capacity building through technical workshops, joint research programmes, and cross-border demonstration projects. These efforts help close gaps in policy implementation, access to technology, and institutional capacity, especially in emerging economies. In particular, APEC promotes inclusive and gender-sensitive energy strategies and recognises the critical role of multi-stakeholder engagement in achieving an equitable energy transition [24]. Despite significant progress, urban energy systems in many APEC economies still face challenges such as fossil fuel dependence, fragmented governance, and inadequate financing mechanisms. However, APEC's multilateral framework provides a solid foundation for collective action. By fostering regional cooperation and aligning national strategies with common sustainability goals, APEC continues to be a key driver of the urban energy transition across the Asia-Pacific region.

2.3. Energy Transition and Environmental Impact

Guixian Tian et al. examine the key factors influencing the adoption of modern renewable energy in selected APEC countries from 1997 to 2023, focusing on their implications for sustainable development and environmental sustainability [25]. From a sustainability perspective, these findings highlight the need for APEC economies to prioritize energy efficiency, strengthen international cooperation, and implement inclusive policies that support renewable energy transitions.

The shift from fossil fuels to renewable energy is central to reducing urban greenhouse gas emissions, as cities account for most global energy-related CO_2 emissions [26]. Urban energy transitions are shaped by spatial structure, infrastructure networks, and institutional capacity [27]. Compact urban planning, mixed land use, and transit-oriented development can reduce transport demand and improve building energy efficiency, thereby lowering overall energy consumption [28]. Empirical studies show that urban form influences energy intensity and infrastructure performance: higher-density environments can enable district heating and cooling networks, centralized renewable integration, and smart grid deployment [29,30]. However, density alone does not ensure sustainability; poorly managed urban growth may increase congestion, pollution, and infrastructure strain [31].

Renewable energy deployment has been widely associated with reductions in carbon intensity and ecological footprints [32,33], particularly when combined with grid modernization and energy efficiency measures. Investment in renewables can also enhance energy security and resilience, especially in regions vulnerable to fossil fuel price volatility and geopolitical risks [34,35]. However, recent studies caution that the environmental benefits of renewables are context-dependent. Nonlinear relationships between renewable energy use and emissions suggest that rapid electricity demand growth or weak regulatory frameworks may offset potential gains [36,37]. These findings underscore the importance of integrated urban energy planning rather than isolated technology adoption.

Industrial and regulatory frameworks also influence urban energy outcomes. Green technological innovation, environmental regulation, and carbon disclosure policies have been shown to accelerate the shift toward cleaner energy systems and reduce fossil fuel dependence [38–41]. Case studies such as Canada's decarbonization of heating systems and Scandinavian district energy models demonstrate how coordinated policy, infrastructure investment, and renewable integration can significantly reduce urban emissions [42–44]. The literature confirms that energy transition in urban environments requires coordinated planning, technological innovation, and institutional capacity. However, there is limited analysis of how regional platforms such as APEC shape these processes across diverse member economies, particularly in translating regional commitments into localized urban implementation.

2.4. Gaps in Existing Research Regarding APEC's Impact on Urban Energy Transitions

Although a growing body of literature addresses APEC's role in regional energy policy, critical gaps remain regarding its specific impact on the urban energy transition. Most studies focus on national energy policy, cross-border energy trade, or renewable energy targets at the macro level, often overlooking the unique dynamics and challenges faced by cities, which are the main centres of energy consumption and emissions. There is little empirical analysis of how APEC's energy transition initiatives affect local urban planning, infrastructure investment, or governance reforms at the city level. Furthermore, while projects such as the Low Carbon Model Town (LCMT) and the Energy Smart Communities Initiative (ESCI) are often cited as successful urban initiatives led by APEC, few peer-reviewed studies have systematically examined their long-term outcomes, scalability, or the transferability of their policies to different urban contexts. There is also a lack of disaggregated data on how APEC programmes have impacted urban energy efficiency, building decarbonisation, the use of renewable energy for heating and cooling, and the adoption of smart grids.

Another unexplored area is the role of multi-stakeholder engagement, including the private sector, city authorities, and civil society, in shaping the urban energy transition in APEC economies. Moreover, comparative studies between APEC economies and other international fora (e.g., EU, ASEAN, or the Global Covenant of Mayors) are scarce, limiting insight into best practices and opportunities for cross-regional cooperation [45]. Addressing these research gaps is critical for understanding the effectiveness of APEC action at the city level and for developing more inclusive, localized, and effective energy transition strategies in the Asia-Pacific region.

3. Methodology

To increase the environmental impact, this study focuses on energy transition. For this purpose, a panel dataset of selected APEC economies, such as China, Japan, and Singapore, was assimilated. This study integrates energy transition and green innovation, which have emerged as promising approaches to mitigating the environmental impacts of human activity, including biodiversity loss and environmental degradation. Therefore, developed and emerging economies are focusing on green innovation and energy transition to tackle the environmental impact. The qualitative policy analysis includes a systematic review of APEC energy policy research, declarations, working group reports and relevant publications from affiliated institutions such as the APEC Energy Working Group (EWG), the Asia Pacific Energy Research Centre (APERC) and the Low Carbon Model Town (LCMT) project. Under the SSP5 ("Fossil-Fueled Development") scenario, economic growth is closely linked to high energy consumption and the continued dominance of fossil fuels.

This research uses the Shared Socioeconomic Pathways (SSPs) framework developed for integrated assessment and climate impact modeling [46]. Of the five narratives, SSP5 (Fossil-Fueled Development) describes a world with rapid economic growth, strong technological progress, and heavy reliance on fossil energy, resulting in high income levels and energy demand [47]. Gross Domestic Product (GDP) projections are obtained from the International Institute for Applied Systems Analysis (IIASA) SSP Database, which provides socioeconomic pathways for climate and energy system modeling [48]. In this study, the scenario is based on SSP5, using GDP (billion USD, 2017/yr) as the variable with annual temporal resolution starting in 2023. GDP values for 2023 are taken either directly at the "World" aggregation level or by summing country-level outputs. When aggregation is required, global GDP under SSP5 is calculated as:

$$\mathrm{GDP}^{\mathrm{SSP5}}_{\mathrm{World},2023} = \sum_{i=1}^{N} \mathrm{GDP}^{\mathrm{SSP5}}_{i,2023} \tag{1}$$

where GDP^{SSP5} denotes the GDP of country or region i in 2023 under SSP5, and N is the total number of countries, which are 3 in our studies. GDP is linked to final energy demand through elasticity-based or econometric formulations of the form.

$$E_t = \alpha \mathrm{GDP}_t^{\beta} \tag{2}$$

where E_t is the total energy demand at time t, GDP_t is the gross domestic product, α is a scaling coefficient, and β is the income elasticity of energy demand [49]. These economies were selected based on their different economic structures, urbanization patterns, engagement in APEC energy initiatives, and environmental impact. The environmental impact of climate change is quantified by calculating CO_2 emissions using the Kaya identity, which links economic activity, energy use, and carbon intensity.

$$\mathrm{CO}_{2,t} = \mathrm{GDP}_t \times \frac{E_t}{\mathrm{GDP}_t} \times \frac{\mathrm{CO}_{2,t}}{E_t} \tag{3}$$

where: GDP_t is gross domestic product at time t, E_t/GDP_t is energy intensity, $\mathrm{CO}_{2,t}/E_t$ is carbon intensity of energy. For each country (China, Japan, Singapore) under SSP5, total emissions are computed as:

$$\mathrm{CO}_{2,c,t} = \sum_s \left(E_{c,s,t} \times EF_s\right) \tag{4}$$

with $E_{c,s,t}$ the energy consumption of fuel s (coal, oil, gas) and EF_s the corresponding emission factor (kg CO_2 per unit of energy). The environmental impact on climate is then assessed through cumulative emissions.

$$\mathrm{CUMCO}_{2,c} = \sum_{t=2023}^{T} \mathrm{CO}_{2,c,t} \tag{5}$$

The case studies draw on national energy transition strategies, city-level planning research, and project reports to assess the effectiveness, scalability, and replicability of APEC-sponsored programmes such as the Energy Smart Communities Initiative and Low Carbon Model Towns. This methodological framework, as shown in **Figure 1**, enables a nuanced understanding of how high-level regional policy interacts with local realities and identifies best practices and persisting gaps in supporting urban energy transition in the Asia-Pacific region, including environmental impact. Criteria for selecting APEC programs and initiatives are analyzed. The following criteria are used to select and evaluate APEC-endorsed programs as shown in **Table 1**.

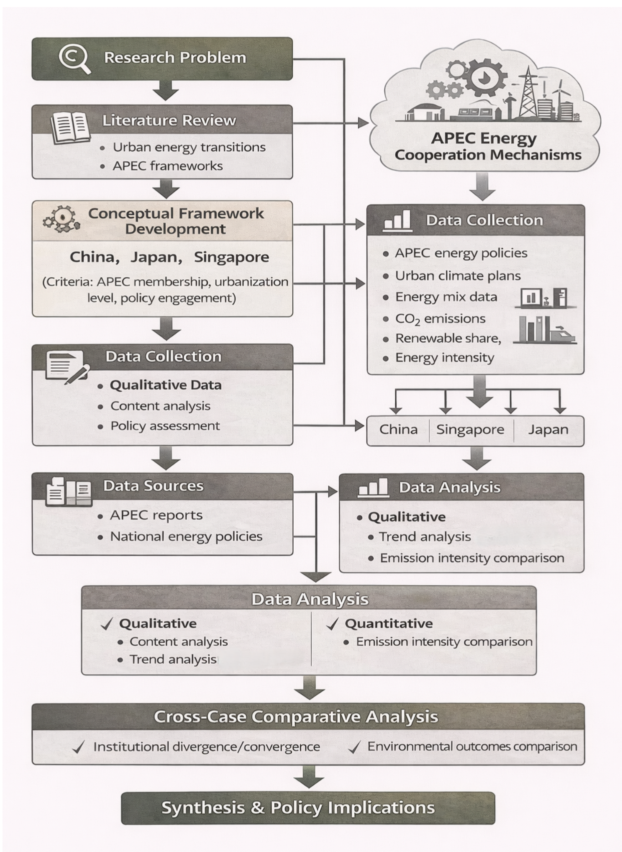

Figure 1. Methodology Flowchart.

Table 1. Criteria for Selecting APEC Programs.

Criterion	Explanation
Alignment with APEC Energy Goals	Supports regional targets such as reducing energy intensity and boosting renewables.
Urban Focus	Specifically targets urban settings and addresses infrastructure, mobility, or planning.
Scalability and Replicability	Designed to be extended or adapted across different APEC member economies.
Integration of Innovation	Incorporates smart technologies, data systems, or low-carbon design.
Public-Private Collaboration	Demonstrates strong partnerships among government, industry, and local actors.
Policy Uptake and Localization	Has been implemented or adapted within local or national policy frameworks.
Monitoring and Evaluation Mechanism	Includes clear performance indicators, reports, and transparency.

4. Result and Discussion

This section presents a comparative analysis of how APEC's regional energy frameworks have been interpreted and implemented at national and local levels in selected member economies: China, Japan, and Singapore. The findings highlight key insights into energy and environmental impact. In the Asia-Pacific context, the selection of APEC programmes and initiatives for analysis is guided by several criteria, including alignment with APEC energy goals, relevance to cities, scalability, technological innovation, and integration into national policy frameworks. In the case of China's Clean Energy Towns program, developed under the APEC-supported Low Carbon Model Town (LCMT) initiative. Another illustrative case is Japan's Smart City Model, which demonstrates the integration of advanced technologies and sustainable design into urban planning. This initiative, developed in line with APEC's Smart Cities and Low Carbon Model Town frameworks, focuses on building resilient, low-carbon urban environments through digital infrastructure, renewable energy integration, and community-driven innovation. A third compelling example is Singapore's Urban Sustainability Framework (USF), which serves as a practical guide for cities to plan, implement, and evaluate sustainability strategies in line with APEC's energy and low-carbon development goals. The focus is on energy efficiency, climate resilience, and sustainable mobility. **Table 2** shows the comparative environmental implications.

Table 2. Comparative Environmental Implications.

Dimension	China	Japan	Singapore
Main pressure type	Emissions scale & land degradation	Carbon lock-in & coastal stress	High per-capita footprint & climate vulnerability
Energy structure under SSP5	Coal & oil dominated	Fossil + nuclear/liquefied natural gas (LNG)	Imported natural gas & oil
Climate change contribution	Very high (global driver)	High (advanced economy)	Moderate total, high per capita
Ecosystem risk	Rivers, soils, air quality	Coastal & urban ecosystems	Coastal, urban heat, water security

4.1. Environmental Impact

Under SSP5, rising GDP and fossil fuel dominance increase energy demand and carbon intensity, resulting in systematic growth in annual and cumulative CO_2 emissions. This amplifies global warming, sea-level rise, and ecosystem stress. **Figure 2** shows the illustration of the SSP5 scenario. Under the SSP5 ("Fossil-Fueled Development") scenario, economic growth is closely tied to high energy consumption and the continued dominance of fossil fuels. As a result, the GDP levels observed in 2023 for China, Japan, and Singapore lead to differentiated but significant environmental pressures. China's very large GDP under SSP5 in 2023 implies: high CO_2 emissions from coal- and oil-dominated power and industrial sectors, severe air pollution ($PM_{2.5}$, NO_x, SO_2) from heavy industry, transport, and power generation. Even with improvements in energy efficiency, the scale effect outweighs the intensity effect, and absolute emissions and resource extraction continue to rise. Under SSP5, mitigation policies are weak, so economic growth directly leads to higher greenhouse gas concentrations. China thus becomes the principal driver of global environmental degradation in Asia under this pathway. Japan's high-income economy has lower energy intensity, yet under SSP5. Carbon lock-in persists due to continued reliance on fossil fuels and LNG. Environmental impacts are moderated by advanced pollution control and efficiency standards, but absolute decarbonization is not achieved. The country experiences partial decoupling between GDP and local pollutants, but not between GDP and cumulative CO_2 emissions, contributing to long-term climate change and sea-level rise risks. Although Singapore's total GDP is small in absolute terms, SSP5 implies very high per capita energy use and CO_2 emissions. Strong dependence on imported fossil fuels, making its carbon footprint largely embedded in regional supply chains, coastal vulnerability to sea-level rise and storm surges, exacerbated by global warming induced by SSP5 emissions. Environmental pressure is thus spatially externalized, emissions and resource depletion occur upstream (fuel extraction, power generation in neighboring countries), while Singapore bears the climate risk exposure.

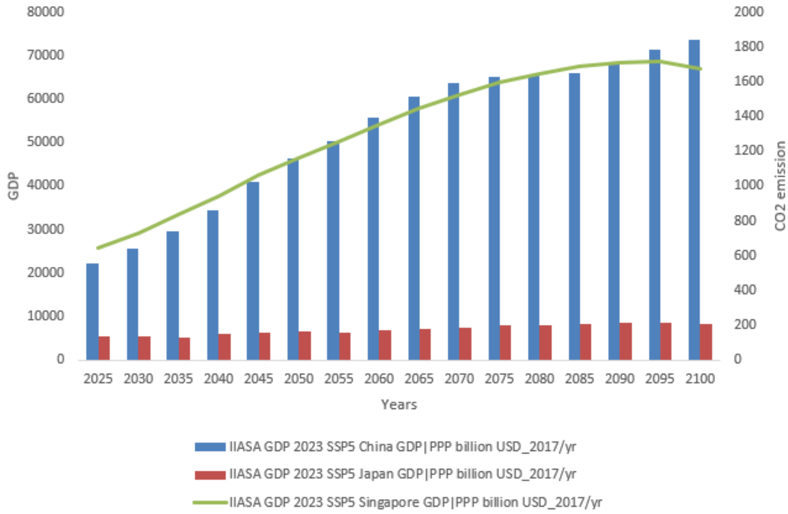

Figure 2. SSP5 Scenario of China, Singapore and Japan.

Under the SSP5 (fossil-fueled development) pathway, rapid GDP growth in China, Japan, and Singapore in 2023 is projected to result in persistently high and, for China and Singapore, increasing CO_2 emissions, as efficiency improvements are outweighed by rising energy demand and the continued dominance of fossil fuels. **Figure 3** shows a clear increase in CO_2 emissions under the SSP5 scenario for China, Japan, and Singapore, driven by rapid economic growth and the continued dominance of fossil fuels in the energy mix which determine radiative forcing and temperature increase. In China, expanding industrial activity and coal-based power generation cause a strong rise in absolute emissions, making it the main contributor to cumulative regional and global carbon output. Japan experiences a more moderate but persistent increase or stabilization at high levels, reflecting efficiency gains that are not sufficient to offset its carbon-intensive energy structure. In Singapore, although total emissions remain small in absolute terms, high per-capita energy use and the expansion of petrochemical and transport activities produce a noticeable upward trend, with a significant share of the carbon footprint embodied in imported energy and traded goods.

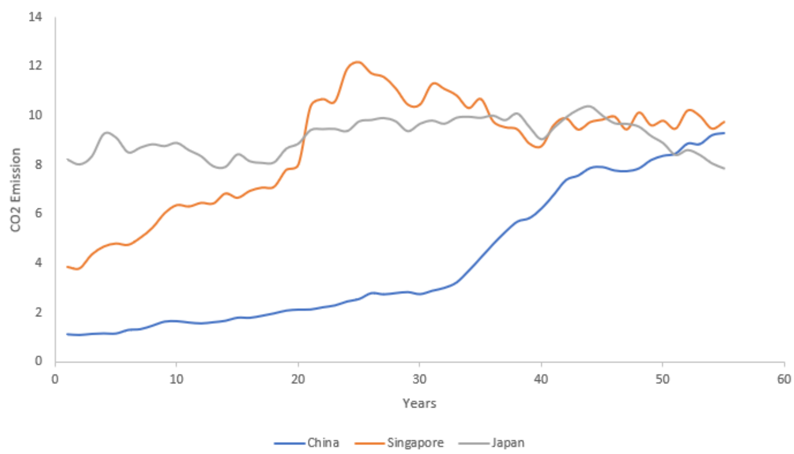

Figure 3. CO_2 Emission.

4.2. Implementation Effectiveness

The effectiveness of implementing APEC-funded urban energy transition programs varies across member economies due to differences in government structures, technical capacity, and resource availability. In China, a strong central government enables efficient coordination and rapid deployment of clean energy infrastructure, resulting in significant progress in integrating renewable energy and electrifying public transportation in target cities. Japan's approach emphasizes technological innovation and community engagement, using advanced Internet of Things (IoT) systems and partnerships with the private sector to optimize energy consumption and support decentralized energy networks. Singapore combines robust policy frameworks with comprehensive data monitoring and urban planning tools to ensure continuous assessment and adaptation of sustainability strategies. While all three economies have implemented successful programs, challenges remain, such as inter-agency coordination, funding constraints, and ensuring equitable access, particularly in smaller cities or less developed regions. These differences highlight the importance of tailoring APEC initiatives to the local context to maximize their impact. The effectiveness of implementation depends on institutional capacity, access to finance, and local governance structures. China has demonstrated strong top-down coordination, enabling the rapid deployment of renewable energy infrastructure and the electrification of public transportation. Japan has demonstrated advanced technology integration and community involvement, particularly in energy monitoring and demand-side management. Singapore has focused on data management, integrated urban planning, and policy benchmarking, positioning itself as a regional model for sustainable urban development.

4.3. Scalability and Replicability

The potential for scaling and replicating APEC-supported urban energy transition programs depends on local economic, institutional, and technological conditions. China's Clean Energy Cities program, with its strong governance and focus on infrastructure upgrades, provides a scalable model well-suited to rapidly urbanizing, industrial economies that can leverage centralized planning. Japan's smart city model, though technologically advanced and innovative, requires significant technical expertise and institutional capacity, making it more appropriate for mature urban economies with strong private sector involvement and robust digital infrastructure. Singapore's Urban Sustainability Framework features a modular design and adaptability, enabling cities with varying resources and governance systems to customize their sustainability goals and monitoring practices. Collectively, these programs show that while there is no universal model, APEC initiatives offer flexible frameworks that can be tailored to different urban contexts in the Asia-Pacific region, fostering regional knowledge sharing and the progressive harmonization of sustainable urban energy policies. All three programs could be adopted by other APEC cities, though with varying degrees of adaptability: China's model can be emulated in industrialized cities with strong government oversight; Japan's model requires high technical and institutional capacity and is thus more suitable for advanced urban economies; Singapore's framework is highly modular and adaptable, making it appropriate for both developed and developing cities seeking a structured sustainability roadmap.

4.4. Key Success Factors and Challenges

Analysis of APEC programs reveals several critical success factors that increase the effectiveness of urban energy transition efforts. First, strong political commitment, as seen in China's central government mandates and Singapore's long-term planning, is essential for pooling resources and maintaining program momentum. Second, cross-sector collaboration among government, private sector, and academia plays a central role, especially in Japan's smart city model, which thrives on technological innovation and stakeholder engagement. Third, integrating digital tools for data monitoring and system optimization improves transparency and adaptive management, helping cities track performance and adjust strategies in real time.

Despite these strengths, challenges remain in all case studies. A key issue is fragmented governance, where overlapping responsibilities between municipal and national authorities can lead to inefficiencies or policy misalignment. In addition, limited technical and financial capacity, especially in smaller or less developed cities, makes it difficult to fully implement the models supported by APEC. Finally, the lack of a standardized monitoring and evaluation framework makes it difficult to compare progress between cities and systematically scale up successful initiatives. To overcome these obstacles, APEC needs to provide more support for institutional capacity building, promote integrated governance models, and improve data sharing mechanisms among member economies. Success factors identified in all cases include strong political commitment at national and local levels, clear legal frameworks and financial incentives, cross-sector partnerships and public-private collaboration, and the use of digital technologies and open data platforms. Common challenges include fragmented administration and coordination problems between authorities, limited funding or technical expertise in smaller cities, difficulties in measuring long-term impact, and ensuring community engagement.

In the future, APEC can enhance its role by promoting cross-border demonstration projects (e.g., smart city corridors, regional energy grids), strengthening public-private partnerships through innovation funding and start-up engagement, and incorporating the principles of climate resilience and just transition more explicitly into the urban energy framework, as shown in **Table 3**. These actions can reinforce APEC's strategic position in global climate policy while promoting inclusive, low-carbon urban development across the region.

Table 3. Opportunities for Future Cooperation.

Criteria	China's Clean Energy Cities Program	Japan's Smart City Model	Singapore's Urban Sustainability Framework
Program Focus	Clean energy adoption, district heating, transit electrification	Smart infrastructure, IoT, decentralized energy systems	Structured sustainability planning, benchmarking, and monitoring
Policy Alignment	Linked to China's 14th Five-Year Plan and carbon neutrality targets	Aligned with METI policies and APEC Smart Cities initiative	Aligned with APEC energy and sustainability goals, supported by global partners
Implementation Approach	Centralized government-led deployment	Collaborative multi-stakeholder innovation	Data-driven, modular framework for urban planners
Technology Integration	Renewable energy systems, electric transit	IoT, energy management systems, electric vehicles (EVs)	Emphasis on sustainability indicators and climate resilience
Scalability & Replicability	High potential in industrializing cities	Applicable mainly in advanced economies with strong tech capacity	Highly adaptable for diverse city contexts
Public-Private Partnership	Strong government-led with some private sector involvement	Extensive collaboration with private companies and academia	Collaborative governance involving multiple stakeholders
Monitoring & Evaluation	Ongoing performance tracking via APERC and local agencies	Advanced energy monitoring and demand-side management	Structured benchmarking and indicator tracking
Key Outcomes	Reduced emissions, improved urban air quality	Innovative smart city solutions, energy efficiency gains	Enhanced urban sustainability planning and data transparency

5. Conclusion

This study examined how the Asia-Pacific Economic Cooperation (APEC) shapes urban energy transitions and assessed the environmental implications of these efforts. The findings indicate that APEC plays a catalytic role in steering low-carbon urban development through policy coordination, knowledge exchange, and capacity-building mechanisms, rather than through binding regulatory authority. Its influence is evident in the alignment of national and municipal energy strategies with regional low-carbon frameworks. The comparative analysis of China, Japan, and Singapore shows that APEC-inspired initiatives are implemented through diverse governance models. China demonstrates a centralized, state-led approach to clean energy city programs. Japan highlights the role of technological innovation and decentralized urban governance in advancing smart energy systems. Singapore exemplifies an integrated, data-driven sustainability framework that enables systematic benchmarking and performance management. Across cases, institutional coordination and technological integration are critical enabling factors. Regarding environmental impacts, APEC-aligned urban energy policies contribute to renewable energy deployment, improved energy efficiency, and reductions in greenhouse gas emissions, along with co-benefits such as enhanced air quality and urban resilience. However, outcomes depend on domestic administrative capacity, financial resources, and effective monitoring systems. Persistent challenges include ensuring equitable access to clean energy, strengthening evaluation frameworks, and promoting inclusive participation in transition processes. This study concludes that APEC meaningfully shapes the direction and architecture of urban energy transitions in the Asia-Pacific region, but its environmental effectiveness is mediated by local governance conditions. Strengthening technical assistance, institutional capacity, and cross-economy collaboration will be essential to enhance the depth, equity, and long-term sustainability of urban energy transformation across APEC economies.

Author Contributions

Conceptualization, Z.L.; methodology, W.S.-H.K.; software, W.S.-H.K.; validation, P.X.; analysis, Y.H.; resources, Z.L.; data curation, Y.H.; original draft preparation, W.S.-H.K.; review, P.X.; supervision, W.S.-H.K.; project administration, Z.L. All authors have read and agreed to the published version of the manuscript.

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Conflicts of Interest

The authors declare no conflict of interest.

AI Use Statement

The authors declare that no artificial intelligence (AI) tools were used in the preparation of this manuscript.

References

[1] Asia-Pacific Economic Cooperation, 2024. About us. Available from: https://www.apec.org/who-we-are/about-us (cited 30 December 2025).

[2] Farghali, M., Osman, A.I., Umetsu, K., et al., 2022. Integration of Biogas Systems into a Carbon Zero and Hydrogen Economy: A Review. Environmental Chemistry Letters. 20(5), 2853–2927. DOI: https://doi.org/10.1007/s10311-022-01468-z

[3] Lund, H., Skov, I.R., Thellufsen, J.Z., et al., 2022. The Role of Sustainable Bioenergy in a Fully Decarbonised Society. Renewable Energy. 196, 195–203. DOI: https://doi.org/10.1016/j.renene.2022.06.026

[4] Moya, D., Aldás, C., Kaparaju, P., 2018. Geothermal Energy: Power Plant Technology and Direct Heat Applications. Renewable and Sustainable Energy Reviews. 94, 889–901. DOI: https://doi.org/10.1016/j.rser.2018.06.047

[5] Nopriantoko, R., 2023. Unlocking Indonesia's Energy Potential: Extracting Clean Energy From Sea and Saline Brines. In Proceedings of the 41st Conference of the ASEAN Federation of Engineering Organisations (CAFEO 41), Bali, Indonesia, 20–23 November 2023; pp. 162–172.

[6] Sosa, M., Ivanova, A., 2025. APEC Cities: Climate Hazards, Adaptation Plans, and Mitigation Actions. Current Urban Studies. 13(1), 25–46. DOI: https://doi.org/10.4236/cus.2025.131002

[7] Roberts, B., Lindfield, M., Steinberg, F., 2017. Sustainable Development Agenda for APEC Cities. Available from: https://www.apec.org/docs/default-source/publications/2017/6/partnerships-for-the-sustainable-development-of-cities-in-the-apec-region/toc/16-sustainable-development-agenda-for-apec-cities.pdf (cited 30 December 2025).

[8] Singh, B., Sharma, S.K., Syal, P., 2021. Net Zero Energy Building Design. Journal of the Institution of Engineers (India): Series A. 102(1), 237–247. DOI: https://doi.org/10.1007/s40030-020-00500-1

[9] Vihurskyi, B., 2024. Optimizing Urban Traffic Management with Machine Learning Techniques: A Systematic Review. In Proceedings of the 2024 2nd International Conference on Advancement in Computation & Computer Technologies (InCACCT), Gharuan, India, 2–3 May 2024; pp. 403–408. DOI: https://doi.org/10.1109/InCACCT61598.2024.10551137

[10] Yannis, G., Kondyli, A., Georgopoulou, X., 2014. Investigation of the Impact of Low Cost Traffic Engineering Measures on Road Safety in Urban Areas. International Journal of Injury Control and Safety Promotion. 21(2), 181–189. DOI: https://doi.org/10.1080/17457300.2013.796387

[11] Yin, Y., Choi, K., Jeong, H.D., et al., 2022. Integration of Schedule, Cost, Traffic, and Risk into the Determination of Construction Contract Times. Journal of Management in Engineering. 38(6), 04022061. DOI: https://doi.org/10.1061/(ASCE)ME.1943-5479.0001089

[12] Ren, H., Sun, Y., Albdoor, A.K., et al., 2021. Improving Energy Flexibility of a Net-Zero Energy House Using a Solar-Assisted Air Conditioning System with

Thermal Energy Storage and Demand-Side Management. Applied Energy. 285, 116433. DOI: https://doi.org/10.1016/j.apenergy.2021.116433
[13] Kechagias, E.P., Gayialis, S.P., Konstantakopoulos, G.D., et al., 2019. Traffic Flow Forecasting for City Logistics: A Literature Review and Evaluation. International Journal of Decision Support Systems. 4(2), 159–176. DOI: https://doi.org/10.1504/IJDSS.2019.104556
[14] Kraus, L., Proff, H., 2021. Sustainable Urban Transportation Criteria and Measurement—A Systematic Literature Review. Sustainability. 13(13), 7113. DOI: https://doi.org/10.3390/su13137113
[15] Lee, E.-B., Ibbs, C.W., Thomas, D., 2005. Minimizing Total Cost for Urban Freeway Reconstruction with Integrated Construction/Traffic Analysis. Journal of Infrastructure Systems. 11(4), 250–257. DOI: https://doi.org/10.1061/(ASCE)1076-0342(2005)11:4(250)
[16] Liu, M., Rasdorf, W., Hummer, J.E., et al., 2013. Preliminary Engineering Cost-Estimation Strategy Assessment for Roadway Projects. Journal of Management in Engineering. 29(2), 150–157. DOI: https://doi.org/10.1061/(ASCE)ME.1943-5479.0000137
[17] Abou-Senna, H., Radwan, E., Navarro, A., et al., 2018. Integrating Transportation Systems Management and Operations into the Project Life Cycle from Planning to Construction: A Synthesis of Best Practices. Journal of Traffic and Transportation Engineering. 5(1), 44–55. DOI: https://doi.org/10.1016/j.jtte.2017.04.006
[18] Daszkiewicz, M., 2019. The Energy–Momentum Conservation Law in Two-Particle System for Twist-Deformed Galilei Hopf Algebras. Modern Physics Letters A. 34(3), 1950024. DOI: https://doi.org/10.1142/S021773231950024X
[19] Onifade, S.T., Alola, A.A., Erdoğan, S., et al., 2021. Environmental Aspect of Energy Transition and Urbanization in the OPEC Member States. Environmental Science and Pollution Research. 28(14), 17158–17169. DOI: https://doi.org/10.1007/s11356-020-12181-1
[20] Khan, I., Xin, C., 2025. The Intersection of Energy Transition and Urban Planning for Sustainable Development: Enhancing Energy Efficiency and Sustainability. Gondwana Research. 152, 142–156. DOI: https://doi.org/10.1016/j.gr.2025.08.018
[21] Horii, N., 1998. APEC Cooperation and Strategies for the Introduction of Renewable Energy into Developing Countries. APEC Study Center, Institute of Developing Economies: Chiba, Japan.
[22] Wang, S., 2016. Making Buildings Smarter, Grid-Friendly, and Responsive to Smart Grids. Science and Technology for the Built Environment. 22(6), 629–632. DOI: https://doi.org/10.1080/23744731.2016.1200888
[23] Ness, D.A., Xing, K., 2020. Consumption-Based and Embodied Carbon in the Built Environment: Implications for APEC's Low-Carbon Model Town Project. Journal of Green Building. 15(3), 67–82. DOI: https://doi.org/10.3992/jgb.15.3.67
[24] True, J., 2008. Gender Mainstreaming and Regional Trade Governance in Asia-Pacific Economic Cooperation (APEC). In: Rai, S.M., Waylen, G. (Eds.). Global Governance: Feminist Perspectives. Palgrave Macmillan: London, UK. pp. 129–159. DOI: https://doi.org/10.1057/9780230583931_7
[25] Tian, G., Hua, X., Li, D., et al., 2025. How energy intensity and global energy dynamics shape renewable energy transition in APEC economies. Geoscience Frontiers. 16(6), 102134.
[26] Kaghembega, W.S.-H., Chen, S., Tchewafei, A., et al., 2024. Modeling and scenario analysis of residential building energy conservation in cities of different weather. Energy Reports. 11, 2670–2684. DOI: https://doi.org/10.1016/j.egyr.2024.02.025
[27] Poumanyvong, P., Kaneko, S., 2010. Does Urbanization Lead to Less Energy Use and Lower CO_2 Emissions? A Cross-Country Analysis. Ecological Economics. 70(2), 434–444. DOI: https://doi.org/10.1016/j.ecolecon.2010.09.029
[28] Luo, S., Yuan, Y., 2023. The Path to Low Carbon: The Impact of Network Infrastructure Construction on Energy Conservation and Emission Reduction. Sustainability. 15(4), 3683. DOI: https://doi.org/10.3390/su15043683
[29] Oluokun, O.A., Akinsooto, O., Ogundipe, O.B., et al., 2024. Integrating Renewable Energy Solutions in Urban Infrastructure: A Policy Framework for Sustainable Development. International Journal of Multidisciplinary Research and Growth Evaluation. 5(1), 1035–1048.
[30] Fayiah, M., Kallon, M.K., 2025. Energy Efficiency and Smart Grid Technologies for Environmental Sustainability. In: Ogwu, M.C., Chibueze Izah, S. (Eds.). Evaluating Environmental Processes and Technologies. Springer: Cham, Switzerland. pp. 439–462. DOI: https://doi.org/10.1007/978-3-031-85327-2_13
[31] Yan, Y., Liu, H., Wang, N., et al., 2021. How Does Low-Density Urbanization Reduce the Financial Sustainability of Chinese Cities? A Debt Perspective. Land. 10(9), 981. DOI: https://doi.org/10.3390/land10090981
[32] Doytch, N., Narayan, S., 2016. Does FDI Influence Renewable Energy Consumption? An Analysis of Sectoral FDI Impact on Renewable and Non-Renewable Industrial Energy Consumption. Energy Economics. 54, 291–301. DOI: https://doi.org/10.1016/j.eneco.2015.12.010
[33] Bhuiyan, M.A., Zhang, Q., Khare, V., et al., 2022. Renewable Energy Consumption and Economic Growth Nexus—A Systematic Literature Review. Frontiers in Environmental Science. 10, 878394. DOI: https://doi.org/10.3389/fenvs.2022.878394
[34] Minh, T.B., Van, H.B., 2023. Evaluating the Relation-

ship between Renewable Energy Consumption and Economic Growth in Vietnam, 1995–2019. Energy Reports. 9, 609–617. DOI: https://doi.org/10.1016/j.egyr.2022.11.074
[35] Jahangir, J., Aman-Ullah, A., 2024. Climate Change Mitigation via Green Investment and Energy Consumption: The Mediating Role of Energy Efficiency. International Journal of Business and Technopreneurship. 14(1), 79–94. DOI: https://doi.org/10.58915/ijbt.v14i1.310
[36] Huang, W., Ortiz, G.G.R., Kuo, Y.-L., et al., 2022. The Non-Linear Impact of Renewable Energy and Trade on Consumption-Based Carbon Emissions. Fuel. 324, 124423. DOI: https://doi.org/10.1016/j.fuel.2022.124423
[37] Chen, X.H., Tee, K., Elnahass, M., et al., 2023. Assessing the Environmental Impacts of Renewable Energy Sources: A Case Study on Air Pollution and Carbon Emissions in China. Journal of Environmental Management. 345, 118525. DOI: https://doi.org/10.1016/j.jenvman.2023.118525
[38] Shah, S.A.R., Naqvi, S.A.A., Anwar, S., 2020. Exploring the Linkage among Energy Intensity, Carbon Emission and Urbanization in Pakistan: Fresh Evidence from Ecological Modernization and Environment Transition Theories. Environmental Science and Pollution Research. 27(32), 40907–40929. DOI: https://doi.org/10.1007/s11356-020-09227-9
[39] Wang, H., Zeng, Y., Zhang, J., et al., 2025. Sustainable Performance Analysis and Environmental Protection Optimization of Green Entrepreneurship-Driven Energy Enterprises. Humanities and Social Sciences Communications. 12(1), 104. DOI: https://doi.org/10.1057/s41599-025-04396-9
[40] Zeng, H., Chau, K.Y., Waqas, M., 2023. Does Green Finance and Renewable Energy Promote Tourism for Sustainable Development: Empirical Evidence from China. Renewable Energy. 207, 660–671. DOI: https://doi.org/10.1016/j.renene.2023.03.032
[41] Ma, B., Lin, S., Bashir, M.F., et al., 2023. Revisiting the Role of Firm-Level Carbon Disclosure in Sustainable Development Goals: Research Agenda and Policy Implications. Gondwana Research. 117, 230–242. DOI: https://doi.org/10.1016/j.gr.2023.02.002
[42] United Nations Economic and Social Commission for Asia and the Pacific (ESCAP), 2021. Shaping a Sustainable Energy Future in Asia and the Pacific: A Greener, More Resilient and Inclusive Energy System. ESCAP Publications Office: Bangkok, Thailand.
[43] Zaidan, E., Ghofrani, A., Abulibdeh, A., et al., 2022. Accelerating the Change to Smart Societies—A Strategic Knowledge-Based Framework for Smart Energy Transition of Urban Communities. Frontiers in Energy Research. 10, 852092. DOI: https://doi.org/10.3389/fenrg.2022.852092
[44] Evers, G., Chappin, M.M., 2020. Knowledge Sharing in Smart Grid Pilot Projects. Energy Policy. 143, 111577. DOI: https://doi.org/10.1016/j.enpol.2020.111577
[45] Aste, N., Del Pero, C., Leonforte, F., 2022. Toward Building Sector Energy Transition. In: Asif, M. (Ed.). Handbook of Energy Transitions. CRC Press: Boca Raton, FL, USA. pp. 127–150. DOI: https://doi.org/10.1201/9781003315353-9
[46] Tebaldi, C., O'Neill, B.C., 2020. Climate Scenarios and Their Relevance and Implications for Impact Studies. In: Sillmann, J., Sippel, S., Russo, S. (Eds.). Climate Extremes and Their Implications for Impact and Risk Assessment. Elsevier: Amsterdam, The Netherlands. pp. 11–29. DOI: https://doi.org/10.1016/B978-0-12-814895-2.00002-1
[47] Rahmani, O., Rezania, S., Beiranvand Pour, A., et al., 2020. An Overview of Household Energy Consumption and Carbon Dioxide Emissions in Iran. Processes. 8(8), 994. DOI: https://doi.org/10.3390/pr8080994
[48] Rodrigues, E., Tinseth, J., Pajek, L., et al., 2025. Forecasting Global Building Internal Heat Gains to 2100: An Applied XGBoost Model Driven by Shared Socioeconomic Pathways. Energy and Buildings. 350, 116642. DOI: https://doi.org/10.1016/j.enbuild.2025.116642
[49] Colelli, F.P., 2023. The Energy Requirements for Rising Adaptation Needs: Mechanisms and Impacts [Master's Thesis]. Ca' Foscari University of Venice: Venice, Italy.