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Editorial: Urban economic aspects of energy, exergy, and environmental sustainability

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Editorial on the Research Topic
Urban economic aspects of energy, exergy, and environmental sustainability

With a mushrooming urban population, cities have become the stage for all the sustainable development challenges and opportunities. More than two-thirds of the world's energy is consumed by urban areas, which account for over 70% of carbon emissions. Thus, cities become critical focal points for energy efficiency and environmental sustainability. The pace of urbanization, combined with the rapid growth of economies, imposes an urgency for cities to adopt an integrated approach to balancing growth and environmental stewardship.

Against this backdrop, the integration of smart technologies and the conducting of energy and exergy analyses have emerged as powerful tools for triggering sustainable urban development. Smart city systems, empowered by digitalization, artificial intelligence, and data analytics, stand at the threshold of promoting energy efficiency, optimizing resource use, and enhancing the quality of urban life. Exergy analysis, on the other hand, presents a rigorous thermodynamic framework for evaluating the effectiveness of energy use in urban systems, revealing aspects that conventional energy analysis might overlook.

This Research Topic, "*Urban Economic Aspects of Energy, Exergy, and Environmental Sustainability*" showcases multi-disciplinary work investigating the relationship between urban economic systems, energy optimization, and environmental impact. In addition to technical efficiency, the articles also consider economic rationale underpinning success-such as cost-effectiveness, financial viability, and return on investment. Collectively, such studies will highlight the potential of exergy-based approaches and innovations in smart urban living to bring the transition to low-carbon, resilient, and economically robust cities.

Exergy is the maximally useful work a system can do as it approaches thermal and mechanical equilibrium with its environment. It represents the usable part of energy-the part convertible into actual work. In definition, exergy is the quality or usefulness of

the energy and not the mere quantity of it. It indicates how much of that energy could practically be turned into a mechanical or electrical output.

Integrating smart technologies and economic sustainability

The first paper in the special edition, "*Digital Innovation, Institutional Environment and Air Quality Improvement*" (Ren et al.) explores the direct impact of digital transformation on city environmental performance. The study shows that the use of digital technologies can significantly improve air quality by optimizing monitoring, enforcement, and energy use, provided these activities operate within a strong institutional framework. The findings indicated that technological innovation and governance reforms can work in synergy to reduce emissions while still maintaining the competitiveness of the economy.

In addition, "*Heterogeneous Effects of the Digital Economy on High-Quality Green Development of Urban Economy and Its Spatial Spillovers: Evidence from the Upper Yangtze River Economic Belt*" (Fan et al.) provides insights into how the digital economy enhances urban sustainability by considering both spatial and economic dimensions. By assessing cities in the Upper Yangtze River Economic Belt, the study found that, while digital innovation spurs economic development, it also plays an important role in enhancing green development and boosting positive spillovers on neighboring regions. This demonstrates the significance of regional cooperation and a shared innovation ecosystem in driving sustainability targets.

Policy, planning, and urban transformation

Policies decide how urban sustainability outcomes will be. The paper entitled "*Did Urban Agglomeration Development Planning Policies Accelerate Urban Population Decline? A Quasi-Natural Experiment Based on Urban Agglomeration Development Planning Policies in China*" (Jiang et al.) gives a more nuanced assessment of China's urban planning policies and their population implications. It speaks to how somewhat well-intentioned development plans can produce complex or sometimes unintended effects over time. The findings emphasized the importance of embedding demographic and spatial considerations into urban economic policies in order to ensure truly sustainable and equitably shared growth.

Likewise, the study entitled "Does City-County Merger Improve Urban Carbon Emission Efficiency? *An Empirical Analysis Based on the Difference-in-Differences Model*" (Fan and Xu) provides empirical evidence on the carbon efficiency-increasing content of an administratively induced restructuring scheme. Through a difference-in-differences model, the analysis indicated that city-county mergers can improve energy efficiency and environmental governance, reducing the carbon footprint. This publication provides valuable communication to policymakers, considering adjustments in the institutional framework as tools for sustainability transitions.

Social perception and human dimensions of smart cities

Not only is urban sustainability a technical or economic matter, it is also very much a social matter. The issue of smart cities and their future implications for city buildings remains largely human-centered in the paper "*Perceptions of Value from Smart City Dubai, an Expatriate View: a Data Report*" (Brown and Han). In reviewing how expatriates think about and value smart city initiatives, the study offers an exceptional perspective on how diverse urban populations might engage with transformational technology. Aligning smart urban development with citizens' expectations will enable energy and infrastructure innovations to enhance the quality of their lives. This research reinforced that social acceptance and inclusivity are as vital as technological sophistication in achieving true sustainability.

Artificial intelligence and exergy for environmental decision-making

The paper entitled "*Agentic Rulebooks Using Active Inference: an Artificial Intelligence Application for Environmental Sustainability*" (Constant et al.) presents an AI application for environmental sustainability and offers a particularly innovative contribution. This paper presents a novel framework through the application of active inference-an AI cognitive mode—in environmental systems. It conceptualizes urban energy management as a dynamic inference problem, thus accommodating adaptive decision-making and minimizing the environmental uncertainty. As showcased in this study, AI could bridge complex urban data systems with actionable sustainability strategies-nurturing the intelligent self-regulatory cities of tomorrow.

Energy, exergy, and economic integration

The common string that connects the six papers is that energy and exergy efficiencies are indeed technical goals, but they also constitute prime economic imperatives. Cities are dense networks of energy use-from transportation and buildings to industrial zones-and the losses are ultimately incurred economically for any failure. Through exergy analysis, efficiency loss is revealed more qualitatively, indicating where energy is wasted or lost, and thus enables progressives and engineers to suggest priority interventions based on maximizing returns.

Such applications of exergy in city design enable cities to move beyond mere energy- saving measures. They identify alternative sources from which heat combined with power may be derived, including on-site renewable energy sources or those near where waste heat can be recovered or used for optimization at district levels. This often counts as two advantages: a promise of lower operating costs and resultant better environmental performance. These new planning approaches make exergy-based methods, together with economic assessment tools such as cost-benefit

analysis, life-cycle costing, etc., the basis of making sustainable development scientifically sound as well as financially feasible.

Toward sustainable and resilient urban economies

The larger purpose behind this special edition is to affirm the connection between urban economic health and environmental resilience. Smart cities must not operate just efficiently but also maintain economic vitality while providing countermeasures against environmental risks. Together, the articles show that sustainability comes along with the chance of economic growth rather than being a burden. The cities stand to gain from sustainability as a trump card to lure investment, catalyze innovation, and better the livability of the urban environment through digital intervention, governance modernization, or AI-led optimization.

By incorporating economic metrics along with energy and exergy analysis, this body of work provides a holistic framework to assess the real costs and benefits of urban sustainability initiatives. It shows how improvements in resource efficiency directly translate into economic competitiveness and social wellbeing—the basis for sustainable urbanization.

These studies show how better governance, digital technologies, and smart environmental strategies can improve urban sustainability. They highlight gains in carbon efficiency, smarter AI-based decision-making, positive impacts of the digital economy, insights into smart-city experiences, the unintended effects of planning policies on population trends, and the role of digital innovation in improving air quality. Overall, they reveal how cities can become greener, smarter, and more resilient.

- Does city-county merger improve urban carbon emission efficiency
- Agentic rulebooks using active inference: an artificial intelligence application for environmental sustainability
- An expatriate view of the perceived values from smart city Dubai: A data report
- Heterogeneous effects of digital economy on high-quality green development of urban economy and its spatial spillovers: evidence from Upper Yangtze River Economic Belt
- Did urban agglomeration development planning policies speed up urban population decline
- Digital innovation, institutional environment and air quality improvement

Conclusion

This Research Topic emphasizes the critical need for economic and thermodynamic investigations to realize the advances of second-generation sustainable cities. The six papers, combined, highlight how energy, exergy, and economic perspectives can come together in the creation of smarter, cleaner, and more resilient cities.

From digital innovation in air quality management to AI-led environmental decision- making, policy reforms in carbon efficiency, and human-centered smart city evaluation, the research paints a comprehensive picture of how technology and the economy can together contribute to sustainability.

We, as editors, hope this Research Topic serves as an inspiration for further interdisciplinary research and encourages our policymaker, planner, and engineer friends to embrace an integrated approach to balancing economic prosperity with environmental responsibility. The road to sustainable urbanization can come from the blend of technological intelligence, economic thrift, and ecological sensitivity—ensuring future cities thrive as engines of growth and sustainability.

Author contributions

HM: Supervision, Conceptualization, Validation, Resources, Writing – review & editing. OY: Project administration, Visualization, Writing – review & editing. AE-F: Validation, Resources, Writing – review & editing. AA: Methodology, Supervision, Validation, Resources, Writing – original draft.

Conflict of interest

The authors declare that this work was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

Generative AI statement

The author(s) declared that generative AI was not used in the creation of this manuscript.

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