Addressing Malaysia's Carbon Footprint: Role of green building technologies

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Abstract

Green building issues accelerated the adoption of renewable energy since building consume substantial amounts of energy and contribute significantly to greenhouse gas emissions which effect to the building performance. This study investigates the role of renewable energy specifically solar, wind, biomass, and geothermal sources in optimizing green building performance. Mixed method combination of literature review and interview the related professionals from diverse backgrounds. Result shows excessive energy consumption, CO_2 emissions, poor environmental quality, outdated technology and rising operational costs impact to green building performance. In conclusion, utilization of green building technology integrates with environmental sustainability significantly optimize green building performance.

Keywords: Renewable Energy; Green Buildings; Sustainable Development; Energy Efficiency

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1.0 Introduction

Advancing sustainable urban development requires the integration of renewable energy sources into green building design and construction. This approach is driven by the urgent need to combat climate change and reduce the environmental impacts associated with conventional energy use in the built environment. The scope of this investigation spans a wide array of renewable energy technologies, with a particular focus on solar photovoltaic (PV) systems, building monitoring systems (BMS), and other innovative solutions designed to enhance the energy performance of green buildings (Nurdiawati A. et al., 2025).

Ahmed, A., et al. (2022) provide a comprehensive assessment of both the challenges and opportunities associated with incorporating renewable energy into building construction. Their analysis explores technical barriers, economic viability, and the critical influence of policy frameworks in shaping effective integration strategies. Beyond these aspects, the study emphasizes the role of stakeholder engagement, advances in construction technologies, and the implementation of novel design approaches. By analyzing both constraints and enabling factors, this research deepens understanding of the complexities surrounding renewable energy adoption in green buildings and offers strategic recommendations for future application.

Equally important, sustainable urban growth requires a holistic perspective that recognizes the interrelationship between renewable energy integration and broader environmental considerations (Chen, L., et al., 2023). In their study *Towards Net-Zero: Assessing the Environmental Impact of Renewable Energy Integration in Green Buildings*, the authors examine life cycle assessments and environmental footprints to evaluate overall sustainability. Their findings reveal that while renewable technologies significantly reduce carbon emissions and reliance on fossil fuels, their production, installation, and maintenance phases create environmental impacts that must be carefully managed. Accounting for these trade-offs allows policymakers and planners to develop strategies that maximize long-term environmental benefits while minimizing unintended consequences.

With respect to solar technologies, two major types can be identified: solar thermal collectors (STCs) and photovoltaic (PV) systems. Solar thermal technologies are commonly applied for domestic hot water (DHW) generation, space heating, and cooling, while PV systems produce electricity for a wide variety of purposes, including powering appliances, lighting, heating, cooling, and hot water supply (Allouhi, H. et al., 2022). These technologies provide significant advantages for building operations, with some advanced systems capable of independently meeting all space heating and DHW requirements, thereby substantially reducing reliance on external energy sources. In addition, solar applications can be effectively integrated with building monitoring systems (BMS) to optimize energy usage and improve overall operational efficiency.

Currently, solar energy contributes approximately 28% of renewable energy utilization globally, reflecting its rapid and sustained growth in recent years. This expansion has been largely facilitated by the continuous decline in PV technology costs, consistent improvements in conversion efficiency, and widespread adoption supported by policy instruments such as feed-in tariffs, tax incentives, green financing, and renewable energy targets. Furthermore, the scalability of solar technologies makes them adaptable for both residential and commercial applications, ranging from small rooftop installations to large-scale solar farms. These developments underscore the importance of solar energy as a cornerstone of renewable energy strategies, demonstrating its critical role in promoting energy security, environmental sustainability, and long-term economic viability.

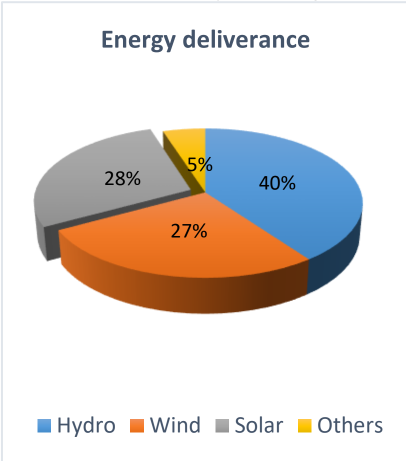

Chart 1: Energy Deliverance (%)
(Source: RESos,2022)

2.0 Literature Review

2.1. High Energy Consumption and Emission in Green Buildings

The building sector plays a pivotal role in global energy consumption and greenhouse gas emissions, accounting for nearly 40% of total energy use and around 30% of CO_2 emissions worldwide (Khan, I. et al., 2021). In light of the increasing urgency of climate change, green buildings have emerged as a sustainable solution, integrating energy-efficient designs, innovative materials, and advanced technologies to minimize negative environmental impacts. Although renewable energy technologies have made remarkable progress, their integration into green buildings is often fragmented and lacks a comprehensive approach that fully considers site-specific conditions, unique energy demand profiles, and long-term cost-effectiveness.

Despite the rising popularity of green building initiatives, the adoption of renewable energy systems (RES)—including solar photovoltaic (PV), wind, and geothermal technologies—remains limited. This underutilization poses a considerable challenge to achieving net-zero energy targets and effectively reducing the carbon footprint of the built environment (Qiang, G. et al., 2023).

This research examines a wide range of renewable energy technologies, with particular focus on solar PV systems, building monitoring systems (BMS), and other innovative methods designed to improve energy efficiency in green buildings (Bilec, M., 2016). By integrating renewable energy solutions, green buildings not only lower environmental impacts but also realize long-term financial savings. These benefits emerge through reduced utility costs, diminished reliance on external fossil-based energy, and access to government incentives or subsidies that encourage renewable adoption. Additionally, incorporating technologies such as solar panels, wind turbines, and geothermal systems enhances resilience against volatile energy prices, increases operational efficiency, and strengthens property market value. Over time, such strategies support broader sustainability objectives and contribute significantly to the transition toward more resilient, low-carbon urban environments (DiPietro, R.B., 2019).

2.2. Climate Change as a Global Inequality Crisis

According to Mansouri, S., et al. (2023), global warming has led to a significant rise in greenhouse gas concentrations. The intensification of global warming poses severe risks to human well-being and is projected to increase the incidence of heat-related mortality. Climate change also represents an issue of international justice, as its most severe consequences are disproportionately borne by vulnerable populations, particularly in developing countries. Moreover, rising global temperatures exacerbate energy demand in urban areas, where the increased reliance on air conditioning and cooling systems results in higher electricity consumption and places additional strain on existing infrastructure. This, in turn, creates a feedback cycle in which elevated energy use contributes further to greenhouse gas emissions, amplifying the effects of climate change. Global warming also intensifies the urban heat island (UHI) effect, which occurs largely due to the dry, dense, and non-permeable nature of building materials that absorb and retain heat more readily in city centres compared to suburban areas. Consequently, urban environments experience considerably higher temperatures than rural surroundings.

To address challenges related to thermal regulation, Zhao, K., et al. (2024) introduced a novel polyvinyl alcohol/graphene/aminated multi-walled carbon nanotube-modified phase-change material (PGAMF) film. This material demonstrates outstanding flexibility and superior thermal regulation properties. The PGAMF achieves a high photothermal conversion efficiency of 88.8% and is capable of retaining heat effectively, maintaining surface temperatures well above ambient conditions in low-temperature environments. Its unique sandwich-like structure enhances mechanical strength, while the encapsulated phase-change materials enable latent heat storage. These combined features make the PGAMF particularly suitable for personal climate control and energy-efficient applications, especially in cold regions and under conditions of weak solar radiation.

2.3. Disputes over CO_2 and Resources Management

The discourse on CO_2 emissions and natural resources extends beyond environmental concerns, encompassing both geopolitical and socioeconomic dimensions. Competition among nations for limited natural resources can give rise to tensions, conflicts, and broader geopolitical challenges. Additionally, the extraction and exploitation of these resources often carry significant social and economic consequences, particularly for local communities and indigenous populations. Complex trade-offs emerge when evaluating the relationship between CO_2 emissions and resource use. While reducing emissions is vital for mitigating climate change, it is equally important to account for the wider implications and ensure a just transition. This requires addressing social and economic inequalities, encouraging sustainable practices, and investing in clean and renewable technologies (Bekun, F. V. et al., 2023). Furthermore, the study highlights that a notable share of greenhouse gas (GHG) emissions originates from the services sector, particularly from high-rise buildings, which represent a growing challenge for sustainable urban development.

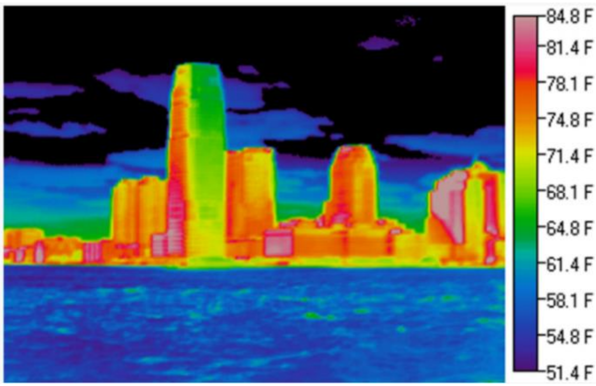

Figure 1 Urban Heat Island effect
(Source: popsci.com)

The Building Management System (BMS) plays a pivotal role in the operation of green buildings, offering significant potential to improve energy efficiency, indoor environmental quality, and overall sustainability. Continuous advancements in research and technology are steadily enhancing BMS capabilities, driving the evolution of green building practices. According to Qiang, G., et al. (2023), the integration of sensor technologies within BMS enables real-time monitoring of energy consumption, allowing data-driven decision-making that helps reduce carbon footprints. Similarly, Bharadwaj, G. (2024) highlights the importance of BMS in maintaining healthy indoor environmental conditions, thereby supporting the well-being and productivity of building occupants.

Beyond its role in energy monitoring and maintenance, BMS serves as a key enabler of renewable energy integration. Advanced platforms can optimize the performance of solar panels, energy storage systems, and demand-response strategies, ensuring a dynamic balance between supply and demand. This functionality not only decreases dependence on external energy sources but also strengthens resilience against power grid instabilities. In addition, BMS is increasingly used to track water usage, monitor lighting efficiency, and regulate ventilation systems, offering comprehensive insights that enable facility managers to adopt more sustainable operational practices.

The transition toward smart buildings is accelerating BMS development, with technologies such as artificial intelligence (AI) and the Internet of Things (IoT) enabling predictive analytics and automated responses to different environmental conditions. Jahan, F., et al. (2025) further emphasize the role of BMS in predictive maintenance, which enhances operational efficiency, reduces downtime, and minimizes resource wastage. As green building standards advance, BMS research and innovation continue to prioritize interoperability, data analytics, and machine learning applications to deliver adaptive and intelligent building performance management.

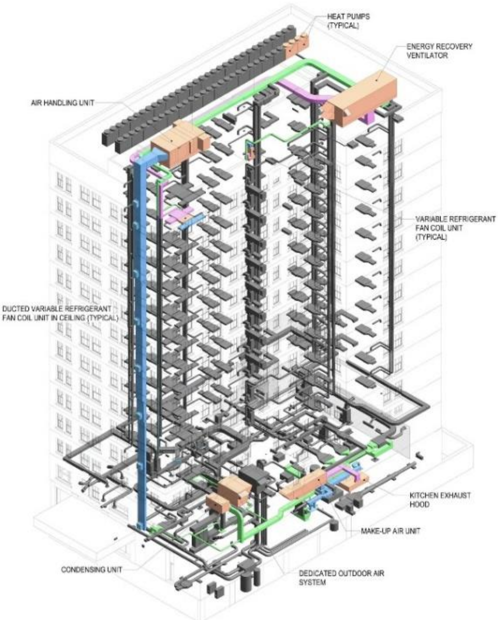

Figure 2: BMS element *(Source: cim.io/blog/bms)*

BMS also plays an essential role in supporting regulatory compliance by streamlining processes required for certifications such as LEED, BREEAM, and Malaysia's Green Building Index. By automating data collection and reporting, BMS not only reduces administrative burdens but also strengthens transparency and accountability. Looking ahead, the convergence of BMS with digital twins and cloud computing is expected to revolutionize building operations further, enabling the creation of self-learning systems that continuously refine performance and align with long-term sustainability goals.

2.4. Barrier to Integrating Low-Carbon Energy

A range of challenges continues to obstruct the effective integration of renewable energy and advanced sustainable technologies within green buildings. Among the most pressing barriers are high upfront investment costs, technological constraints, limited stakeholder awareness, and restrictive policy or regulatory environments. The lack of standardized frameworks for assessing cost-effectiveness further complicates decision-making, leaving building owners and policymakers struggling to weigh long-term benefits against initial expenditures. While innovations such as renewable energy systems and controlled temperature building shells (CTBS) have the potential to reduce energy demand, lower operational costs, and enhance environmental performance, concerns over payback periods and return on investment slow their adoption. This issue is particularly evident in regions where energy is subsidized or priced relatively low, making financial incentives for sustainable retrofits less persuasive. The intermittency of renewable energy sources, coupled with the demand for reliable storage solutions, adds further layers of complexity and cost. Compounding the issue are insufficient technical expertise, weak enforcement of regulations, and a lack of long-term financing mechanisms, all of which discourage wider implementation of sustainable construction practices. Without stronger institutional backing, coherent policy frameworks, and wider awareness efforts, renewable energy adoption in green buildings is likely to remain gradual despite its clear potential (Kylili & Fokaides, 2017).

Another limiting factor is the absence of holistic planning that accounts for site-specific conditions, energy consumption patterns, and life-cycle cost analysis. Although incentives and subsidies are available, they are often fragmented, short-term, or inadequate to close financial gaps needed for large-scale deployment. Thus, the issue extends beyond technical feasibility to economic viability. Without innovative financing mechanisms, stable regulatory environments, and stronger recognition of long-term benefits, technologies such as renewable systems and CTBS will continue to face resistance. Furthermore, uncertainty surrounding future energy prices, fluctuating policy commitments, and evolving green building standards heighten the financial risks perceived by stakeholders. Too often, advanced sustainable technologies are viewed as optional upgrades rather than integral design components, further delaying widespread use. The key challenge, therefore, lies not only in lowering costs but also in shifting stakeholder mindsets while creating reliable policy frameworks that provide stability and predictability for long-term investments.

Equally significant is the insufficient integration of renewable energy strategies into broader urban and regional planning. While single buildings may achieve energy efficiency gains, the lack of coordinated approaches across neighbourhoods or cities limits the collective benefits of green technologies. For example, renewable systems such as solar photovoltaics or CTBS deliver greater effectiveness when implemented at the district or community scale, supported by shared infrastructure and smart energy management systems. However, fragmented governance structures and competing stakeholder priorities often prevent this level of collaboration. Adding to these challenges is the scarcity of long-term performance data on emerging technologies. Without credible benchmarks and case studies, investors remain hesitant to commit substantial capital, especially in developing regions. Addressing this gap requires greater collaboration between research institutions, governments, and the private sector to generate reliable datasets, establish pilot projects, and share knowledge broadly. Ultimately, overcoming these obstacles demands a systemic approach that combines financial innovation, regulatory stability, technological progress, and cultural acceptance to accelerate the adoption of renewable energy and CTBS in green buildings (Kylili & Fokaides, 2017).

Growing environmental pressures and rising energy costs have made efficient building energy management more critical than ever. Lighting inefficiencies represent a significant source of wasted energy, especially in indoor spaces where natural daylight remains underutilized. Studies indicate that improper lighting practices can result in up to 30% excess energy use when lights are left on in unoccupied areas. This highlights the urgent need for advanced strategies that merge technical solutions with behavioural interventions. One promising approach is the use of occupancy sensors and daylight analysis systems. Occupancy sensors minimize waste by ensuring that lights are switched off in empty spaces, while daylight sensors adjust artificial lighting in line with natural light availability. Together, these systems not only reduce electricity demand but also improve user comfort by maintaining appropriate illumination levels in response to both human presence and environmental conditions.

Emerging technologies such as computer vision and artificial intelligence (AI) offer even greater potential. As noted by Xie, C., et al. (2023), these tools move beyond traditional sensors by providing detailed insights into occupancy trends, activity recognition, and even user preferences. With the help of AI-driven models, buildings can predict lighting needs with high accuracy, ensuring lights are activated only when necessary. This predictive capability reduces unnecessary electricity consumption, smooths demand fluctuations, and extends the lifespan of lighting systems. Integrating natural daylight with artificial lighting further strengthens efficiency, as spaces with both high daylight availability and occupancy achieve significant reductions in electricity demand. In addition to energy savings, exposure to natural light supports occupant health and productivity by regulating circadian rhythms, enhancing mood, and improving overall well-being.

From a broader sustainability standpoint, reducing lighting-related waste contributes meaningfully to climate goals by lowering building carbon footprints. Given that lighting accounts for a considerable share of total building energy use, even modest efficiency improvements can lead to measurable reductions in greenhouse gas emissions. This aligns with global targets for achieving net-zero carbon buildings. However, the adoption of advanced lighting systems is not without challenges. High upfront costs, technological complexity, and the need for specialized maintenance present barriers for building owners. Moreover, privacy concerns linked to computer vision technologies must be addressed to ensure user trust and acceptance. Robust regulatory frameworks and strong data protection policies are therefore essential to balance innovation with ethical considerations.

Policy incentives and awareness campaigns also play a vital role in overcoming adoption barriers. Governments and regulators can promote uptake by offering subsidies, embedding energy efficiency standards into building codes, and publicizing best practices. At the same time, fostering a culture of awareness among building occupants is crucial, as responsible energy behaviour amplifies the benefits of technical interventions. While inefficient lighting remains a critical source of energy waste, the integration of computer vision, AI, and daylight management technologies presents a path toward meaningful change. By aligning technological innovation with policy support and occupant engagement, efficient lighting systems can become a cornerstone of sustainable building management. Ultimately, this integrated approach not only reduces energy consumption and environmental impact but also creates healthier, more comfortable, and more productive indoor spaces, reinforcing the long-term vision of sustainable urban development (Xie, C., et al., 2023).

2.5. Enhancing Building Efficiency and Sustainability with Renewable Energy

Integrating renewable energy into high-rise commercial buildings is critical for enhancing existing green practices and improving overall performance. These buildings can lessen their reliance on carbon-based fuels by adding technology such as solar panels or wind turbines, while also improving energy efficiency, waste reduction, and environmental responsibility. Adopting renewable energy not only reduces carbon emissions, but it also improves operational efficiency, lowers long-term expenses, and helps businesses comply with sustainability certifications. Furthermore, it improves resistance to increased energy consumption and price variations. Exploring how it affects demonstrates the way renewable energy may change high-rise structures into more sustainable and prepared for the future infrastructure.

3.0 Methodology

A literature review and a preliminary study with consenting respondents were used for data collection. The preliminary study, conducted through interviews with Integrated Building Management consisting of Engineers, Facilities Managers, and Project Managers, identified the seriousness of the issue and the significance of the research to the industry. Interviewees were selected based on the buildings they managed that required compliance with green building practices. As the research was still in progress at the time of writing, the data presented reflects only the preliminary findings. The first phase involved a literature review using secondary data from books, journals, theses, dissertations, conference proceedings, and reports, followed by primary data collection through the preliminary study. Table 1 presents the background of this study.

Table 1. Preliminary study and background

Description	Remark
Target Respondent	Facilities Manager Project Managers Engineers
Sampling Frame	Eight (8) respondents from Integrated Building Management
Duration	Two (2) months
Methodology	Interview Discussion
Software of Analysis	Microsoft Excel 2024

Source: Author,2025

4.0 Finding and Discussion

Table 2 summarises the interviewee's background. The research came to an end after eight (8) interviews, and all the responses reflected various perspectives. In the interview, two (4) of the respondents indicated their role as Facilities Manager, followed by two (3) who were Engineers, and one (1) who was Project Manager. Most of the respondents who participated in the survey have vast experience in the renewable energy and green building. According to Table 2, six (6) out of eight (8) interviewees have more than ten (10) years of experience in green building, followed by two (2) of interviewees who have only one (1) to five (5) years of experience in green building. Based on the interviewees' site building, five (5) interviewees have been interviewed at green building 3, two (2) at green building 1 and one (1) at green building 2. The data collected represents that respondents are experienced both in the renewable energy industry and involved in green building. Therefore, the data collected is reliable and suitable for the preliminary study.

Table 2. Summaries on the interviewee's background

Interviewee	Respondent Designation	Experience in the industry	Case Study
Interviewee 1	Facilities Manager	More than 10 years	Green Building 1
Interviewee 2	Facilities Manager	More than 10 years	Green Building 1
Interviewee 3	Facilities Manager	More than 10 years	Green Building 2
Interviewee 4	Facilities Manager	More than 10 years	Green Building 3
Interviewee 5	Project Manager	More than 10 years	Green Building 3
Interviewee 6	Senior Engineer	More than 10 years	Green Building 3
Interviewee 7	Technical Engineer	1 to 5 years	Green Building 3
Interviewee 8	Technical Engineer	1 to 5 years	Green Building 3

Source: Author,2025

The interview results highlighted the underlying reasons necessitating the implementation of the Green Building Index (GBI) in Malaysia, as shown in Table 3. The interviewees were briefed and questioned about six (6) key problems hindering GBI implementation, which were earlier identified through the literature review, such as high energy consumption, greenhouse gas emissions, indoor environment quality, integration challenge, lack of sustainable design and rising operational cost

Table 3. Issues Underlying the Adoption of GBI

Issue	Explanation
High energy consumption	High energy use from lighting, cooling, and ventilation, nearly 40% of total demand and 30% of CO_2 emissions. Reliance on fossil fuels raises costs, harms the environment, and strains resources. Lack of renewable integration, like solar PV, weakens green building goals.
Greenhouse gas emissions	Drives global warming and carbon footprint. Degrades air quality, stressing need for renewables. Rising resource demand threatens long-term viability
Indoor environment quality	Artificial lighting and non-renewable cooling harm indoor comfort Poor air circulation raises health and productivity risks. Lack of renewables hinders sustainable indoor environments.
Integrated technology	Synchronization between systems is often inefficient and complex. Many Building Management Systems (BMS) are outdated and cannot handle renewable inputs effectively. Limited coordination reduces energy efficiency and system reliability. These barriers undermine the full benefits of renewable adoption. Long-term energy and environmental targets remain difficult to achieve. High costs arise from system upgrades and retrofitting.
Lack of sustainable design	Conventional designs prioritize short-term savings over sustainability. Limits renewable energy integration like solar, turbine or BMS Retrofitting is costly and less effective. Reduces impact of renewable systems and slows efficiency goals.
Rising operational cost	Rising costs from inefficient energy use Dependence on conventional power that increases expenses. Higher utility bills burden buildings. Long-term financial strain on building operations. Limited resources for sustainability improvements.

Source: Author,2025

Table 4. Main issues driving the GBI implementation

Interviewee	Issues that driving the GBI implementation
Interviewee 1	Greenhouse gas emissions/ Indoor environment quality
Interviewee 2	Greenhouse gas emissions/ Indoor environment quality
Interviewee 3	High energy consumption
Interviewee 4	Integration challenge/ High energy consumption
Interviewee 5	Integration challenge/ Rising operational cost
Interviewee 6	Integration challenge/ Rising operational cost
Interviewee 7	Integration challenge/ Rising operational cost
Interviewee 8	Lack of sustainable design/ Integration challenge

Source: Author,2025

Preliminary studies show that the key factors driving GBI implementation include greenhouse gas emissions, indoor environment quality, high energy consumption, integration challenges, rising operational costs, and lack of sustainable design. Among these, integration challenges and rising operational costs were mentioned by multiple interviewees, highlighting their critical role in influencing the adoption of GBI practices, while environmental and design-related issues also remain important considerations.

6.0 Conclusion

Reflecting on the above discussion, prioritizing sustainability in the building sector provides wide-ranging benefits that go beyond just environmental protection. It helps reduce reliance on conventional energy, lowers long-term operational costs, and improves indoor comfort for occupants. At the same time, it supports healthier lifestyles, creates more resilient communities, and ensures that resources are used more efficiently. As a conclusion, utilization of green building technology integrates with environmental sustainability and makes buildings become responsible towards economically practical, and socially beneficial, contributing more productive environments.

Article Contribution to Related Field of Study

Aiman Faez Mohd Khazani carried out the research and wrote and revised the article, conceptualised the central research idea and provided the theoretical framework.
Ts. Sr. Dr Mohamad Ridzuan Yahya designed the research, supervised the research progress; anchored the review, and approved the article submission.

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