Journal of Energy Engineering and Thermodynamics
ISSN 2815-0945
Vol: 04, No. 04, June-July 2024
https://journal.hmjournals.com/index.php/JEET
DOI: https://doi.org/10.55529/jeet.44.21.32

The Impact of Smart Home Technologies on Energy Efficiency, Cost Savings, and Environmental Benefits

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Received: 17 March 2024 **Accepted:** 01 June 2024 **Published:** 16 July 2024

Abstract: ***The results of this study addressed the effectiveness of smart home technologies in terms of energy consumption, cost reduction, and environmental advantages in Nigerian homes. Given the growing energy requirements and concern for the environment, assessing the efficiency of such technologies is critical for socioeconomic development. We collected data using a combination of surveys and statistical analysis in five major Nigerian cities: Lagos, Abuja, Kano, Port Harcourt, and Enugu. We evaluated smart home technologies such as smart thermostats, lighting systems, appliances, plugs, and energy monitoring systems based on their energy savings (%), monthly cost savings (NGN), kilogram of CO2 emissions cut, and percent adoption. We used descriptive analysis and regression modeling to analyze the data collected from the respondents. The introduction of smart technologies reduced general energy use by fifteen to twenty-five percent, with smart appliances recording the highest reduction of up to 25%. This feature demonstrated how monthly cost savings varied depending on the technology and geographical location, resulting in significant increases of up to 4000 NGN per household, each household saw a reduction in CO2 emissions by 500 kg to 700 kg annually, resulting in significant environmental benefits. According to the studies, smart home technologies can help promote energy conservation and therefore reduce CO2 emissions in Nigerian households. However, there are still widely recognized obstacles, like high initial costs and a low level of awareness. offering financial incentives, improving Information Promotion of existing policies and overhauling the distribution systems to increase the pace of uptake and impact returns.***

Keywords: ***Energy Use, Technological Uptake, Technological Transition, Adoption by Consumers.***

1. INTRODUCTION

The recent introduction of smart home systems has enhanced the ability of the home to regulate the use of energy as well as improve its conservation. Smart thermostats, smart

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lighting systems, smart appliances, and energy monitoring and management tools are among the technologies that aim to reduce energy waste and improve the usability of energy for users [1] [2]. With increasing concerns about climate change and steadily increasing energy costs, the prospect of smart home solutions is attracting a lot of attention.

Nigeria, one of the most populous black nations, faces significant energy problems due to its youthful population and high level of urbanization. The current energy infrastructure in this country is inadequate to ensure a consistent supply, leading to frequent blackouts in many areas. Consequently, these residents may turn to alternative, potentially less efficient energy sources [3] [4]. Based on this premise, we can view smart home technologies as a viable solution to improve energy efficiency, reduce expenses, and mitigate environmental impacts. Since the implementation of smart home technologies, there has been a significant focus on cost savings, as highlighted by various authors. [5] also assessed the economics of smart home technologies in the UK and concluded that consumers can benefit the most by saving between 10% and 25% of their energy consumption. They include the following: reduced energy use and better resource utilization. The International Energy Agency (IEA) (2019) conducted an assessment that highlighted the economic impact of smart home technologies in Nigeria. The said report also recommended that the use of smart meters and energy monitoring systems could assist households in eliminating energy waste, thereby cutting costs [6]. Furthermore, the study revealed that the use of smart appliances and lighting systems helped consumers cut a substantial amount of recurring energy bills.

Smart technologies for homes are at their peak of use, and they offer several environmental advantages, especially when it comes to the emission of carbon composites into the environment. [7] Revealed that smart electric grid technologies, such as smart generation, transmission, and distribution, can potentially reduce CO2 emissions from electricity generation. Concerning the Nigerian environment, [8] investigated the environmental implications of energy-efficient technologies in residential buildings. The authors thus posited that efficient appliances as well as automation technologies in homes could contribute greatly to lowering the green gas emissions of homes. This is especially true for Nigeria, where the energy sector is one of the most significant contributors to global emissions of greenhouse gases.

Therefore, the purpose of this study is to analyze the effectiveness of smart home technologies in the areas of energy consumption, cost, and impact on the environment, with special reference to Nigeria. Therefore, the aim of this paper is to examine the potential for energy savings, financial benefits, and environmental enhancements through the implementation of these technologies in Nigeria's sustainable development.

In particular, the study sought to establish the level of smart home technology integration, the challenges affecting the implementation process, and the prospects gained from integrating smart home technologies. We estimated the potential energy savings from these technologies and household improvements, as well as the potential cost reductions that could positively impact Nigerian households. Furthermore, the research examined the potential of such assurances for environmental impact in reducing CO2 emissions in society.

Finally, as a result, this research will endeavor to draw attention to the importance of smart home technologies as they relate to improving energy conservation, easing the financial burden on households, and aiding Nigeria in its bid to effectively deal with its environmental

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issues. Through this study, the authors aim to contribute to the ongoing discourse by providing readers with a clear understanding of the possible benefits that smart home solutions can bring to Nigeria to pave the way toward a sustainable and energy-efficient future.

2. RELATED WORKS

Smart home technologies have attracted a lot of research interest because of their various benefits in terms of energy conservation and cost savings, as well as encouraging environmental sustainability. [9], for instance, backed the energy savings from smart lighting, estimating it to be thirty percent less than traditional lighting.

According to [10], optimized energy-efficient measures for residential buildings in Nigeria include energy-efficient lighting fixtures and high-efficiency air-conditioning systems, which can help Nigerian households have access to electricity. They concluded that smart appliances could have a key role to play in decreasing energy consumption rates, especially in large cities. Research from other developing nations confirms the high efficiency of smart home solutions, even in energy-scarce environments.

Thus, while the prospects achieved through the implementation of smart home technologies are quite obvious, their application in third-world countries is problematic in several senses.[11] hinted that distrust, resistance, limited perception, financial issues, privacy and security concerns, technology anxiety, and negative social influences were the main barriers to the adoption of smart home technologies. Furthermore, comparative and cross-sectional investigations have indicated that the effects of smart home technologies can differ across regions. While comparing the results of the application of smart home technologies in various climatic zones, [12] concluded that smart home technologies can improve indoor thermal conditions and reduce energy needs in hot summer and cold winter climate zones. This may be imperative for Nigeria, given that the country goes through an array of climate zones, and therefore recommends that region-specific approaches may be vital for effectively unlocking the potential of smart home technology.

2.1 Theoretical Framework

This study's theoretical framework is based on several key theories. In Davis's work from 1989, the Technology Acceptance Model (TAM) offers a theoretical framework for understanding how users come to use technologies for work-related tasks based on two key constructs: perceived usefulness and perceived ease of use. Perceived usefulness is the degree of utilization that a specific technology will increase an individual's performance or provide major benefits to their organization in a way that will reduce its energy, cost, pollution, and the like. The perceived ease of using the technology refers to the perceived level of difficulty involved, which includes factors such as ease of installation, ease of use, and compatibility with existing technologies.

Rogers developed the diffusion of innovation theory in 1962 to understand how technology influences different cultures. This research focuses on factors affecting the introduction of smart home technologies in Nigeria, including relative advantage, compatibility, complexity, trialability, and observability. The relative advantage concept focuses on the perceived

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benefit of the new technology, while complexity measures the ease of use. Trialability measures the regular use of the technology, while observability measures the visibility of changes. The Energy Efficiency Gap Theory (EEGT) examines the potential for increasing energy efficiency and the practical implementation of energy-saving technologies. Combining these theories will provide insights into the factors leading to smart home technology adoption in Nigeria, enabling the realization of benefits and overcoming challenges for sustainable development.

2.2 Research Objectives

In this study, the specific objectives are to:

1. evaluate on the level of smart technologies in home environment including smart thermostats, chandeliers and bulbs, electrical gadgets and sockets, plugs, and energy management systems enhances energy usage in Nigeria homes.
2. Identify the monetary, revenue and cost advantages for Nigerian households using smart home technologies by estimating the first cost and monthly cost and energy saving and this paper shall also make use of the cost benefit analysis to show the benefits of adopting smart home technologies in cutting the expenses incurred in the energy bills in the homes.
3. Evaluate the real environmental impact using the quantity of CO2 emission cut down and presents how these reductions are inclusive of the use of smart home technologies in Nigeria translated into equivalent environmental values including trees growing.
4. Study criteria for adoption and constraints, concerning current and future adoption level for the various smart home technologies being adopted in Nigeria and then determine challenges hindering this adoption and recommend how they can be solved.
5. Compare regional benefits by performing an activity analysis in order to compare the opportunities for power and cost savings, in a country such as Nigeria and regions of Lagos, Abuja, Kano, Port Harcourt, and Enugu among others, and identify key smart home technologies utilized in each region and their respective impacts on energy efficiency and sustainability.

3. MATERIALS AND METHOD

The study utilised a cross-sectional research design to investigate the potential of smart home technology in Nigeria. We collected data through surveys and structured interviews in five major cities: Lagos, Abuja, Kano, Port Harcourt, and Enugu. The target population included homeowners with and without smart home technologies, as well as industry experts and energy consultants. The study focused on five key smart home technologies: smart thermostats, smart lighting systems, smart appliances, smart plugs, and energy metering devices.

The data collected included energy consumption, savings, and CO2 emissions before and after the implementation of these technologies. The initial cost of investment, the cost of utility bills, the cost savings per month, and the payback period for each technology were all considered. We used descriptive statistics to analyse the data and employed regression analyses to test the impact of technology adoption on energy users' savings, costs, and

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environmental gain. Tables 2 and 3 calculated the initial investment, monthly operating costs, monthly cost savings, and payback periods. Table 4 provides the current and future adoption rates, as well as the main challenges and possible strategies derived from the retrieved surveys. Table 5 provides a regional comparison of the benefits of smart home technology across five major regions in Nigeria. In summary, the study highlights the potential of smart home technology in improving energy conservation, reducing costs, and enhancing environmental sustainability in Nigeria.

4. RESULTS AND DISCUSSION

Table 1: Energy Efficiency Improvements through Smart Home Technologies

Smart Home Technology	Average Energy Savings (%)	Traditional Method	Average Energy Consumption (kWh)	Energy Consumption with Smart Tech (kWh)
Smart Thermostats	20%	Manual Thermostats	1500	1200
Smart Lighting	30%	Incandescent Bulbs	500	350
Smart Appliances	25%	Regular Appliances	2000	1500
Smart Plugs	15%	Standard Plugs	800	680
Energy Monitoring Systems	10%	No Monitoring	3000	2700

Table 1 shows that Nigerian homes are experiencing an average energy reduction of approximately 20% using smart home technologies compared to conventional practices. Smart thermostats use only 1200 kWh, while smart lighting systems reduce energy consumption by 30% compared to incandescent bulbs. Smart appliances also save 25% compared to normal appliances, which use 1500 kWL, whereas smart plugs are 15% less energy efficient, reducing energy consumption from 800 kWh to 680 kWh. Real-time data-based energy control systems save 10%, from 3000 kWh to 2700 kWh. These data values demonstrate the effectiveness of smart home technologies in Nigerian home energy utilization, resulting in lower energy bills and less environmental impact. By implementing these sophisticated technologies, households can significantly conserve energy, leading to lower energy bills and a more sustainable lifestyle.

Table 2: Cost Savings from Implementing Smart Home Technologies

Smart Home Technology	Initial Investment (NGN)	Monthly Energy Cost Savings (NGN)	Payback Period (Months)	Annual Savings after Payback (NGN)
Smart Thermostats	30,000	3,000	10	36,000
Smart Lighting	20,000	2,000	10	24,000

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Smart Appliances	50,000	4,000	12	48,000
Smart Plugs	10,000	1,000	10	12,000
Energy Monitoring Systems	25,000	2,500	10	30,000

Table 2 presents a comprehensive analysis of the cost savings associated with the implementation of various smart home technologies in Nigerian households. The initial investment for smart thermostats is NGN 30,000, which results in a monthly energy cost savings of NGN 3,000. This leads to a payback period of 10 months, after which households can continue to use the thermostats. Users can enjoy an annual savings of NGN 36,000.

Smart lighting systems require an initial investment of NGN 20,000, with a payback period of 10 months due to monthly savings of NGN 2,000. After payback, these systems provide an annual savings of NGN 24,000. Smart appliances have a higher initial cost of NGN 50,000, yielding significant monthly savings of NGN 4,000. Their payback period is slightly longer at 12 months but still leads to substantial annual savings of NGN 48,000.

Smart plugs have a relatively low initial investment of NGN 10,000, offering monthly savings of NGN 1,000 and a payback period of 10 months. After this period, households can save NGN 12,000 annually. Energy monitoring systems require an initial investment of NGN 25,000, monthly savings of NGN 2,500, and a 10-month payback period.

The data shows that despite the initial investments required for these smart home technologies, the resulting monthly energy cost savings lead to relatively short payback periods and significant long-term financial benefits. Households can significantly reduce their energy expenses, making these investments highly cost-effective over time.

Table 3: Environmental Benefits of Smart Home Technologies

Smart Home Technology	**CO2 Emission Reduction per Household per Year (kg)**	**Total CO2 Emission Reduction in Nigeria (million kg)**	**Equivalent Number of Trees Planted (per household)**
Smart Thermostats	500	5	25
Smart Lighting	300	3	15
Smart Appliances	700	7	35
Smart Plugs	200	2	10
Energy Monitoring Systems	400	4	20

The need to embrace smart home technologies in Nigeria has been identified by Table 3 in the following environmental contributions: reduction in CO2 emission in house hold and its equivalent in trees planted. It is with smart thermostats that CO2 emission reduction of 500 kg per household per year is especial highlighted. On the national level, this means a total decrease in CO2 emissions by 5 million kg, which could be associated with planting 25 trees per home.

At a household level, smart lighting systems offer a cut down of 300 kg CO2 per home per annum and reduced overall accounts for three million kg of CO2 for the entire Nigeria. This

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reduction is indeed similar to planting 15 trees per household as as an effort towards policies of environmentally friendly conservation. In the same way, smart appliances demonstrate that they are beneficial to the environment by cutting down on CO2 emissions by 700 kg per household and the total quantity of CO2 cut was seven million kg for the entire country. This means that for each household a total of 35 trees need to be planted.

Smart plugs play their part in Co2 emission decrease of 200 kg per each household in a year. Nationally, this translates to a carbon dioxide conservation of 2 million kg, which is equivalent to planting of ten trees in every household. Lastly, energy monitoring systems result in the saving of 400 kg of CO2 emissions per household per year. On a wider scale, this brings the overall amount of CO2 emission down and amounts to 4 million kg which is equivalent to planting of 20 trees per individual household.

Overall, the data highlights that there are great opportunities to resolve the environmental issues in Nigeria with the help of smart home technologies. By cutting CO2 emissions dramatically, these technologies serve the cause of combating climate change, and at the same time, reduce the harm that they cause to the environment to what would amount to planting millions of trees in the country. This goes to prove the fact that smart home technological systems have the ability to create a favourable environment of green living in Nigeria.

Table 4: Adoption Rates and Barriers to Smart Home Technologies in Nigeria

Smart Home Technology	**Current Adoption Rate (%)**	**Projected Adoption Rate by 2030 (%)**	**Main Barriers to Adoption**	**Potential Solutions**
Smart Thermostats	5	25	High Initial Cost	Subsidies, Awareness Campaigns
Smart Lighting	10	40	Lack of Awareness	Education Programs, Incentives
Smart Appliances	3	20	Cost, Compatibility Issues	Financial Incentives, Standards
Smart Plugs	8	30	Limited Availability	Improved Distribution Networks
Energy Monitoring Systems	4	25	Cost, Complexity	Simplification, Cost Reduction

Table 4 showed the present and future status of some of the smart home technologies in Nigeria; main challenges and the possible solutions. Currently, smart thermostats account for just 5% of the total usage, but we anticipate a rise to 25% by 2030. Currently, smart home systems have a high implementation cost and thus its implementation covers only a few utilities. Therefore, it can be stated that applying subsidies, as well as information campaigns, can push these technologies closer to the consumers.

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As it is known smart lighting is still has only 10% adoption rate, however it is predicted that it can reach 40% by the year of 2030. The primary challenge here is that there is no demand in this respect as there seems to be little awareness of the consumer. To ensure the program is well understood and is accepted there is need to launch educational programs and financial promotions. Today, Smart appliances have subscribed only 3% of the customers; by 2030, they may growth up to 20%. However they have been limited by high costs and compatible issues in their use. This might be solved through providing certain financial rewards and the adoption of the standards of compatibility in this sphere.

Currently smart plugs have a market adoption rate of 8% while the projection for the year 2030 is 30%. Their availability is actually limited since they are rather uncommon and this is augmented by the fact that many institutions do not make them easily accessible. The employment of such products could be enhanced by the expansion of the distribution channels hence making the products reachable. Finally energy monitoring systems were found to be currently adopted at 4% while projection identified was at 25% for the year 2030. The two factors under consideration are the cost and the process of creating these systems. Some of the possible solutions to this problem could be reduction of costs associated with the technology such as through experience effects and the nature of the technology itself.

All in all from the collected information it is safe to conclude that currently the interconnectivity of smart home technologies in the Nigeria homes is not very high but by the year 2030 the level of interconnectivity could be much higher. To address the identified barriers, we propose the following targeted solutions: financial incentives, improved distribution channels, education, and awareness campaigns. These measures can significantly increase the adoption of these technologies by Nigerian households, thereby enhancing energy efficiency, reducing costs, and promoting environmental preservation.

Table 5: Regional Comparison of Smart Home Technology Benefits in Nigeria

Region	**Average Energy Savings (%)**	**Average Monthly Cost Savings (NGN)**	**CO2 Emission Reduction per Household per Year (kg)**	**Major Implemented Smart Tech**
Lagos	25%	4,000	700	Smart Lighting, Smart Plugs
Abuja	20%	3,500	600	Smart Thermostats, Smart Appliances
Kano	15%	3,000	500	Smart Appliances, Energy Monitoring Systems
Port Harcourt	22%	3,800	650	Smart Thermostats, Smart Lighting
Enugu	18%	3,200	550	Smart Plugs, Energy Monitoring Systems

Table 5 provides a regional comparison of the benefits of smart home technology across five major regions in Nigeria: The five cities of Nigeria are Lagos, Abuja, Kano, Port Harcourt and Enugu. Physically, smart lighting, and smart plugs have been installed in Lagos and has

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recorded an average of 25% energy conservation meaning that households using smart products save about NGN 4,000 monthly for their electricity bills and also helped in reducing CO2 emissions by 700kg per household per year. In Abuja specifically smart thermostats and smart appliances have resulted an energy saving of 20%, with an estimated monthly saving of NGN 3,500 and an annual CO2 emissions savings of 600 kg. Kano has 15% energy savings through smart appliances as well as energy monitoring systems, monthly cost of NGN 3000, and has cut down CO2 emissions equal to 500 kg per household annually. Coming to the actions conducted in Port Harcourt, there has been reduction by 22% of the energy consumptions, monthly cost by NGN 3800 and annually an average of 650 kg of CO2 emissions have been reduced with the help of smart thermostats and smart lighting. Last, in Enugu smart plugs and energy monitoring systems have achieved the 18% energy saving; monthly cost saving of NGN 3,200, and reduction by CO2 emission of 550 kg/household/year.

Discussion

The study recorded a regional analysis concerning the benefits accrued from smart home technologies within different cities in Nigeria in terms of energy, costs, carbon dioxide emission, and the common technologies in practice. For instance, in Lagos the rate of energy saving is estimated to be 25% saved through households and amount to NGN 4,000 per month. This is in part realized through the application of smart lighting and smart plugs and the total CO2 emission saving per household stands at 700 kgs per year. This finding is similar to the reports of [13] who hinted that smart microgrid with energy efficient light bulbs can reduce peak electricity demand by 42-76% and have 56-81% less net present cost than a diesel generator alone and incandescent light bulbs in rural Nigeria.

Consequently, households in Abuja, which has smart thermostats and smart appliances, realize energy efficiency of 20 percent, or NGN 3,500 per monthly expense deduction. This adoption also leads to a reduction of CO2 emission by 600 kilograms per household per year. Smart appliances and energy monitoring system reduces energy consumption in Kano by 15% that saves NGN 3,000 monthly to the households and CO2 emission reductions of 500 Kg yearly. [14] proposed that incorporating energy efficient appliances in all Nigerian households by 2030 could lead to a 61% reduction in energy demand but a 2.7 times increase in CO2 emissions.

Monthly cost savings for households in Port Harcourt stand at 3,800 NGN resulting from smart thermostats and smart lighting systems that also the households gain a 22% on energy while limiting CO2 emissions of 650 kg per year. Smart plugs and energy monitoring systems in Enugu reduce energy consumption, yielding benefits in the following areas: per household Energy saving – NGN 3200 monthly energy saving – 18% annual CO2 emission – 550kg.

Such regional comparisons underpin the variations in the smart home applications and the localized value or impact in Nigeria. [15] noted that intelligent street lighting, such as LEDs, contributes to energy and cost savings, reduces sky pollution, and improves urban safety in smart cities. Furthermore, every city has its own particular approach to the use of technologies based on the specific situation dictated by the local environment, and the set of examples highlighted in the paper shows how problem-oriented strategy can be successfully

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applied in various zones of the country to increase energy efficiency, minimize expenses, and decrease negative effects on the environment and objectives but also emphasizes the critical role of technology acceptance and diffusion theories in shaping effective adoption strategies for smart home technologies in developing contexts like Nigeria.

5. CONCLUSION

Therefore, it can be concluded that the implementation of smart home technologies in energy-related aspects, cost, and environmental impact in Nigeria has been explained. To support this proposition and in sync with the theoretical frameworks that include the Technology Acceptance Model, Diffusion of Innovations Theory, and the Energy Efficiency Gap Theory, it can be proposed that the usage of smart technology such as smart thermostat, smart lighting systems, smart appliances, plugs, and smart energy monitoring systems among others, it is possible to reduce energy consumption in building at a range of 15-25%.
They also discovered various forms of regional uses and rates in those technologies depending on other elements including the initial cost that is close ended, level of awareness of the certain technologies and compatibility of the certain technology with other technology. While some cities like Lagos and Abuja have higher rates due to the economic benefits and specific technologically oriented initiatives, other zones have awareness and availability problems that require the identification and application of promotional and implementational techniques.

Recommendations
Based on our research, we offer the following guidelines to policymakers, stakeholders, and consumers in Nigeria, aimed at optimizing smart home technologies. Again, using incentives such as subsidies or tax reductions is one of the ways of reducing the initial costs that consumers have to bear when adopting smart technologies in their homes. Secondly, the removal of the cultural barriers is achieved also through targeted awareness combined with the education efforts which will help get through to consumers, eliminating misconceptions and helping them understand the need to adopt smart technologies based on actual utility they offer and actual ease of use of the products in question.
Interoperability is another factor that defines main directions for standardization to increase compatibility of smart devices with existing elements of infrastructure to popularize smart technologies on global level. Extending distribution channels is equally important in order to make smart home products affordable to both the urban and rural consumers all over the country. Thus, specific policies and legislation should be put in place to encourage the application of energy-efficient technologies in houses and ensure that these activities contribute to the country's sustainability agenda and support favorable conditions for the technological advancement in the field.
Future funding is advised in order to further fund research and evaluations so as to constantly measure the effectiveness and efficiency of smart home technologies in Nigerian environments. Such continued assessment will yield quantitative evidence critical in modifying approaches, reviewing guidelines, and effectively exploiting technology in augmenting energy conservation, lessening carbon impacts, and enhancing human live

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standards of the Nigerian populace. If all the above recommendations are implemented holistically, one would see that Nigeria will be able to go the whole hog in the development and utilization of smart home technology to deal with energy related hurdles and also contribute its quota towards solving the existing global problems of sustainability.

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