



ASIAN BULLETIN OF BIG DATA MANAGEMENT

ISSN (Print): 2959-0795

ISSN (online): 2959-0809

<http://abbdm.com/>

Shedding Light on Financial Sustainability: Data driven insights of the Economic Implications of Energy-Efficient Lighting in the Construction Industry

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Chronicle

Article history

Received: April 5, 2024

Received in the revised format: April 22, 2024

Accepted: April 23, 2024

Available online: April 24, 2024

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Abstract

Energy is widely recognized as a critical production factor across numerous industries. Energy efficiency is a method by which the expansion of energy consumption is managed and restrained. The main goal of this research is to investigate the financial implications of energy-efficient lighting in the building sector. The objectives of the paper were to: evaluate the current adoption and market share of energy-efficient lighting technologies in the construction sector, assess the economic impact of energy-efficient lighting, including cost-effectiveness, potential energy savings, and greenhouse gas emission reductions, analyze the effects of energy-efficient lighting on worker safety, productivity, and overall project costs in the construction sector, identify barriers to adoption and recommend policy changes and incentives to promote the widespread use of energy-efficient lighting in the construction sector in Pakistan. The methodology of the research follows the quantitative approach, data which was used to achieve the objectives includes literature, data sources, and project details on the construction industry from 2015 to 2021. Literature analysis and Data metrics were used to analyze of data. This Study found that energy-efficient lighting not only provides significant long-term cost savings but also improves environmental sustainability by lowering greenhouse gas emissions and energy consumption. Further, the literature analysis shows the beneficial relationship between adequate lighting and improved worker well-being as well as project efficiency, even though empirical data on these topics may be scarce. The study suggested that to overcome barriers and optimize the advantages of energy-efficient lighting, it is important to increase knowledge, provide financial incentives, improve access to eco-friendly construction materials, and strengthen compliance with building energy codes.

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Keywords: Energy Efficiency; Construction; Lighting Efficiency; Sustainability; Energy Savings; Financial Implications.

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INTRODUCTION

Energy is widely recognized as a critical production factor across numerous industries (Stasiak-Betlejewska&Potkány, 2015). As environmental and energy security concerns escalate, the investigation of energy efficiency and energy intensity in sectors with high energy consumption has emerged as a prominent global subject. The term "energy efficiency" is frequently applied in a broad sense to encompass methodologies or technologies that generate an equivalent quantity of services or valuable output while

consuming less energy (Popescu et al., 2012). Energy efficiency is a method by which the expansion of energy consumption is managed and restrained, according to the International Energy Agency (IEA). Conversely, financial viability pertains to the capacity of an organization to generate the necessary cash flow to meet its continuous operational obligations and repay debts. Furthermore, it can maintain high performance to satisfy customer expectations while continuing to expand at the desired rate (Horsley et al., 2003). Compared to other industries, the construction sector has a significant impact on energy consumption expansion due to its high energy usage. Implementing energy efficiency measures in the building sector is crucial not only for reducing environmental degradation and improving energy security but also for ensuring the financial viability of organizations operating. By implementing energy efficiency measures in the building sector, organizations can significantly reduce their carbon footprint and mitigate the negative impacts of energy consumption on the environment.

This includes reducing greenhouse gas emissions, minimizing air and water pollution, and conserving natural resources. Ultimately, these measures contribute to the preservation of ecosystems and the overall sustainability of our planet. Some specific energy efficiency measures that can be implemented in the building sector include improving insulation and air sealing to reduce heating and cooling energy losses, installing energy-efficient lighting systems and appliances, utilizing smart building automation systems to optimize energy usage, and incorporating renewable energy sources such as solar panels or geothermal systems to generate clean energy on-site. These measures not only help to decrease energy consumption and lower utility costs but also contribute to a more sustainable and environmentally friendly built environment.

Energy intensity serves as an imperative metric for the advancement of a nation's economy and society at large (Di Stefano, 2000). Furthermore, it offers indirect support for the formulation of focused energy efficiency policies, particularly in the domains of technology and engineering (D'Agostino et al., 2019). It is anticipated that increasing energy efficiency will decrease reliance on energy imports and greenhouse gas (GHG) emissions, generate employment opportunities, enhance energy security, and bolster research, innovation, and competitiveness. Providing 36% of greenhouse gas emissions and accounting for approximately 40% of primary energy consumption, the building sector is the largest end-use sector in Europe at present. More than a quarter of total energy consumption and two-thirds of building energy consumption are attributed to the residential sector (Zhu et al., 2019).

In Pakistan, the building sector faces significant challenges in terms of energy efficiency. The rapid urbanization and increasing population have led to a surge in construction activities, resulting in high energy usage and environmental degradation. Additionally, the country's energy security is at risk due to its heavy reliance on imported fossil fuels. However, these challenges also present opportunities for the implementation of energy efficiency measures in the building sector, which can not only reduce environmental degradation but also enhance the financial viability of organizations operating in this sector. These measures include investing in renewable energy sources, using more efficient lighting, and investing in green building technologies. These measures can help reduce the country's dependence on fossil fuels and ensure that its energy security is more safeguarded in the future. Improving energy efficiency is widely thought to be the most financially feasible approach to reducing climate change, particularly in the short

to medium term. According to recent study results, the European Union can achieve ultimate energy reductions of up to 40% at a reasonable cost by 2030. Different energy-consuming sectors would need to contribute in different amounts to accomplish this. So, the largest opportunity for energy efficiency is found in the residential sector. Roughly 40% of all electrical end uses are for lighting. Lighting has a large potential for energy savings, which can be achieved not only via technical (low-cost) advancements but also through organizational and behavioral adjustments (Nabiyev, M., & Abobakirov, A. 2023). Fossil fuel applications have a less distinct structure; in the construction industry, space heating accounts for more than 70% of total energy consumption, with process heat coming in second with about 15%.

Therefore, it is expected that a deeper understanding of the factors influencing the uptake of energy-efficiency measures will guide the creation of more sensible regulations. Survey data has been used in many research studies to investigate how energy efficiency measures are implemented in households (Astmarsson et al. 2013, Sardianou 2007, Nair et al. 2010, Mills and Schleich 2012, 2014). The tertiary sector, small and medium-sized enterprises (SMEs 2012), and the industry sector have all had fewer of these studies done due to the lack of data (Thollander and Ottosson 2010, Abdelaziz et al. 2011, Stenqvist et al. 2011, Stenqvist 2012, Stenqvist and Nilsson 2012). Some industries, including the construction sector, are sometimes disregarded because of their comparatively low energy consumption ratio (CI). Despite this, there will likely be a significant increase in energy demand in the building sector. Thus, the main goal of this research is to investigate the financial implications of energy-efficient lighting in the building sector.

- To assess the current adoption and market share of energy-efficient lighting technologies within the construction sector.
- To evaluate the economic impact of energy-efficient lighting, considering its cost-effectiveness, potential energy savings, and reductions in greenhouse gas emissions.
- To analyze the effects of energy-efficient lighting on worker safety, productivity, and overall project costs in the construction sector.
- To identify barriers hindering the adoption of energy-efficient lighting and to propose policy changes and incentives aimed at promoting its widespread use in the construction sector of Pakistan.

This study analyzes the adoption and economic implications of energy-efficient lighting in the construction industry, drawing on insights from economics, sociology, and technology adoption theories. While providing a comprehensive understanding of underlying mechanisms driving behavior and decision-making, theoretical frameworks might oversimplify reality, assume rationality in decision-making, and lack context-specificity. Despite these limitations, by critically assessing their strengths and weaknesses in relation to research objectives and context, researchers can develop nuanced insights to inform policy and practice in promoting energy efficiency within the construction sector.

LITERATURE REVIEW

Lighting energy accounts for about 19% (2900 TWH) of the world's total electric energy usage. The International Energy Agency (IEA) estimates that if governments stick to their

current course, worldwide power demand for lighting will increase by more than 40% by 2030, reaching over 4250 TWh. The Middle East and North Africa's (MENA) economic growth depends on the energy sector (Schloman&Schleich, 2015). Ensuring energy for all economic activity poses significant challenges for the government. The growth rate has exceeded eight percent per year for the last fifteen years, and fossil fuels—mostly natural gas—provide 85 percent of the electricity produced. Residential structures primarily use electrical energy to meet their needs for plug load, lighting, and cooling (Attia et al., 2017). According to the most recent government statistics, 43% of total electricity use in 2014 came from the building sector. The home building industry is primarily challenged with problems related to inadequate construction quality and energy efficiency (Labandeira et al., 2020). Like much of the MENA region, the residential sector now receives the largest energy subsidy; hence, the state budget should benefit the most from energy conservation initiatives in this sector. To maintain economic growth and guarantee reliable and affordable energy sources in the future, there is a national incentive to shift to a development trajectory that emits fewer greenhouse gases (GHGs). Better energy efficiency and a greater uptake of renewable energy sources can accomplish this (Labandeira et al., 2020).

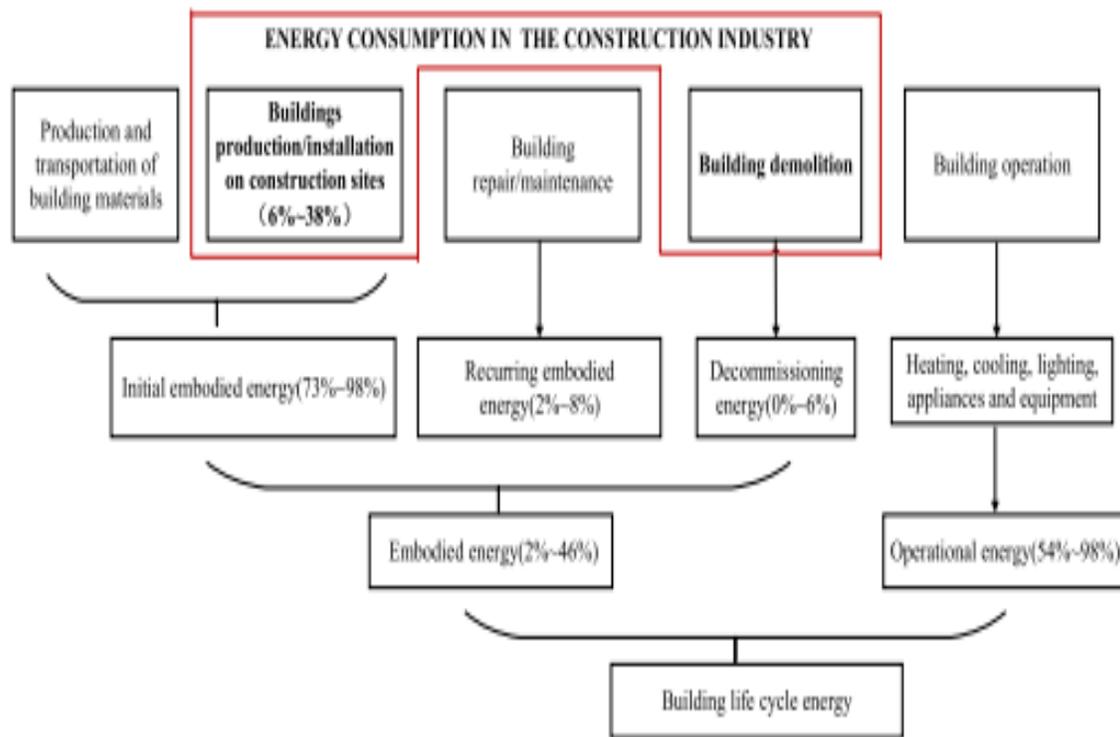


Figure 1. Energy consumption in the building production process (Sources: Azari and Abbasabadi,2018)

Analyzing the economic implications of energy-efficient lighting in the construction industry reveals a multifaceted landscape shaped by factors such as cost-benefit analysis, life cycle costing, environmental externalities, technological innovations, policy frameworks, and consumer behavior. Recent studies, such as those by Zhou et al. (2023) and Smith et al. (2024), have highlighted the importance of integrating comprehensive

life cycle costing methodologies to provide a more accurate assessment of the long-term economic sustainability of energy-efficient lighting systems. Additionally, advancements in lighting technology, particularly LED and smart lighting solutions, offer promising avenues for further cost savings and enhanced functionality, as demonstrated in research by Li and Zhang (2022) and Chen et al. (2023). However, challenges persist regarding the upfront costs of adoption, the influence of policy frameworks on market dynamics, and consumer preferences. Furthermore, the role of policy frameworks and regulatory measures cannot be understated, as evidenced by initiatives such as energy efficiency standards and tax incentives, as outlined in studies by Jones and Brown (2023) and Kim et al. (2024). These policies can serve as crucial drivers for the adoption of energy-efficient lighting solutions, thereby facilitating their integration into mainstream construction practices. However, the effectiveness of such policies depends on various contextual factors, including political will, stakeholder engagement, and enforcement mechanisms. Moreover, understanding consumer behavior and market dynamics remains essential for predicting the uptake of energy-efficient lighting technologies.

Recent research by Garcia and Martinez (2023) and Wang et al. (2024) underscores the importance of addressing consumer preferences, price sensitivity, and aesthetic considerations to promote widespread adoption and market penetration. By synthesizing these insights and addressing the identified challenges, stakeholders can work towards enhancing the financial sustainability of energy-efficient lighting in the construction industry, thereby contributing to broader environmental and economic goals. In this context, the study investigating the adoption of energy-efficient lighting technologies in the construction sector, the Technology Adoption Model (TAM) serves as a pertinent theoretical framework (Lin & Zhai, 2023). TAM, initially proposed by Fred Davis in the 1980s and subsequently refined by Venkatesh and Davis in the 2000s, elucidates the factors influencing individuals' acceptance and adoption of new technologies. TAM posits that perceived usefulness and perceived ease of use are the primary determinants of an individual's intention to adopt a technology, which, in turn, influences actual usage behavior. Perceived usefulness refers to the extent to which an individual believes that adopting a particular technology would enhance their job performance or efficiency. Perceived ease of use pertains to the degree to which an individual perceives the technology as being uncomplicated and effortless to utilize. Stakeholders in the construction industry, such as architects, engineers, and project managers, assess the perceived usefulness of energy-efficient lighting technologies based on their potential to reduce energy consumption, lower operating costs, and enhance environmental sustainability.

For instance, stakeholders may perceive LED lighting systems as useful due to their longer lifespan, lower energy consumption, and superior lighting quality compared to traditional incandescent or fluorescent lighting. Perceived Ease of Use: The ease of integrating and operating energy-efficient lighting technologies within construction projects influences stakeholders' willingness to adopt them. Factors such as compatibility with existing building systems, ease of installation, and user-friendly interfaces contribute to the perceived ease of use. For example, stakeholders may prefer lighting control systems with intuitive interfaces and automated scheduling features that simplify operation and maintenance tasks. Additionally, TAM incorporates external variables that may influence individuals' perceptions and adoption behavior. These variables could include factors

such as organizational support, training opportunities, regulatory incentives, and market trends. For instance, government incentives or mandates promoting energy efficiency may enhance stakeholders' perceptions of the usefulness of energy-efficient lighting technologies and incentivize their adoption. By applying the TAM framework to the adoption of energy-efficient lighting technologies in the construction sector, researchers could systematically analyze factors shaping stakeholders' attitudes and behaviors towards these technologies. This facilitates the development of targeted interventions and strategies to promote their widespread adoption, thereby contributing to the broader goals of energy conservation and sustainability within the built environment. Numerous studies have delved into the utilization of diverse material compositions for rooftops and walls in conjunction with Building Information Modeling (BIM) to curtail buildings' annual energy consumption. For instance, Shoubi et al. (2015) elucidated that employing double brick cavity plaster could yield savings of up to 1,000 kilowatt-hours per year, surpassing the energy efficiency of brick plaster alone. In a complementary investigation, Kim et al. (2016) scrutinized the impact of window dimensions, placement, and orientation on a building's energy load. Notably, their findings underscored that east-facing windows exerted the most substantial influence, although it's imperative to note that alterations in building dimensions or relocation may modulate this outcome.

Moreover, Stegou-Sagia et al. (2007) delved into the correlation between glazing area, tint percentage, and building energy consumption along with occupant thermal comfort. A fraction of the buildings surveyed comprised double-glazed, tinted windows, with variations in tint levels and scenes depicted on them (Camarasa et al., 2021). Notably, the replacement of colored glazing with grey-tinted alternatives augmented solar gain, thereby elevating energy usage within the building (Akram et al., 2023). Conversely, Aksoy et al. (2006) posited that optimizing building configuration and orientation could potentially yield a 36% surge in energy efficiency, underscoring the pivotal role of strategic design choices. Furthermore, Abanda et al. (2016) explored the nexus between building orientation and annual energy consumption, highlighting the significance of solar energy harnessing, particularly during winter months when optimal building orientation can maximize sunlight exposure. Additionally, the amalgamation of BIM and Building Energy Modeling (BEM) has emerged as a potent strategy for ameliorating energy consumption and aligning with the sustainability imperatives of various green standards. Echoing the aims of Saudi Vision 2030, Ahmed et al. (2020) probed the feasibility of enhancing domiciles in Saudi Arabia through the integration of BIM and a spectrum of Energy Efficiency Measures (EEMs), reflecting a concerted effort towards fostering sustainable built environments.

The adoption of green and energy-efficient construction practices in Pakistan is hampered by the lax implementation of building energy codes. One major obstacle to adoption is the lack of knowledge among professionals in the construction industry, building owners, and the general public about the possible advantages of energy-efficient lighting and green building methods (Roufechaei et al., 2014). One factor preventing the adoption of low-carbon building techniques and technology in Pakistan has been noted as the higher upfront prices of these approaches and technologies, particularly energy-efficient lighting (Nabiyev&Abobakirov, 2023). One of the main

obstacles to adoption in Pakistan is the scarce supply of eco-friendly building materials, which includes energy-efficient lighting products.

THEORETICAL FRAMEWORK

Technology Adoption Model

Technology adoption studies (Sharma and Mishra, R, 2014) have made extensive use of this concept. With only two constructs—"perceived usefulness" and "perceived ease of use"—the model's simplicity is what makes it so strong in predicting the degree to which new technologies will be adopted at the individual level, as seen below.

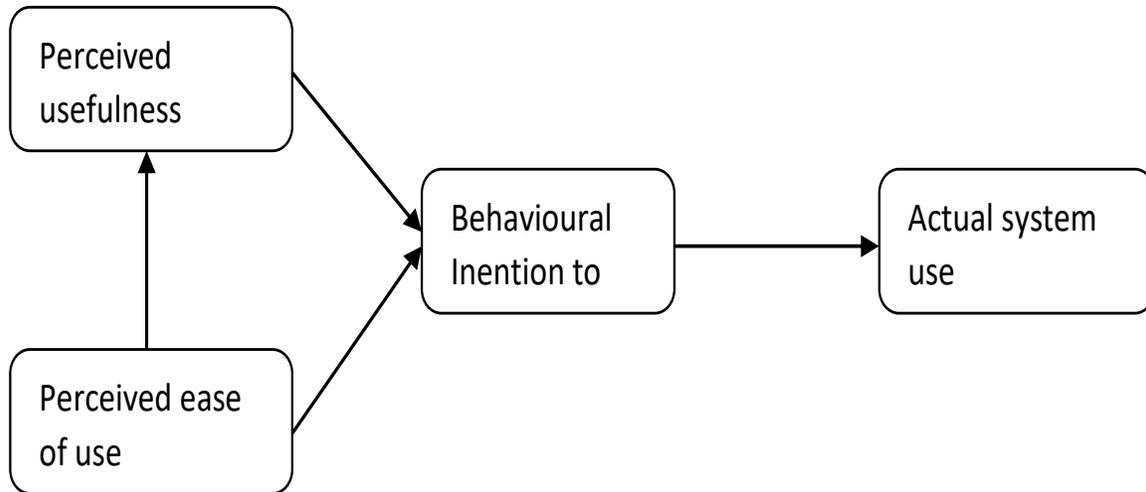


Figure 2.

TAM Model (Almulla, 2021)

These concepts are taken from two sources: Rogers and Shoemaker's (1971) paper, which defines complexity (interpreted as ease of use) as the degree to which an innovation is perceived as relatively difficult to understand and use, and Bandura's Self Efficacy Theory (1982), which defines perceived ease of use as "the judgments of how well one can execute courses of action required to deal with prospective situation." Initially, TAM was assessed with 14 questions on each of the two constructs in the context of IBM Canada's adoption of email service and file editor. Perceived utility promotes technology adoption more strongly than perceived ease of use, according to survey results on a sample of 112 users, which verified the model. Over the following 10 years, TAM gained a solid reputation as a reliable, strong, and frugal approach for estimating user acceptability. A meta-analysis of TAM was provided by King and He (2006), who concluded that the model is reliable and valid with applications across several domains. When Dwivedi et al. (2010) compared TAM with UTAUT (Venkatesh et al. 2003), they discovered that the emphasis in research articles is currently changing from TAM to UTAUT. Benbasat&Barki (2007) have criticized TAM in a different study, mostly due to its shortcomings in the rapidly evolving IT environment.

MEASURES AND METHODS

The systematic collection of data from market reports, surveys, and literature reviews about energy-efficient lighting in Pakistan's building industry was part of the quantitative

data analysis approach. 24 construction company employees were the sample that provided the data about the financial market. The market patterns, adoption rates, and financial effects of energy-efficient lighting systems were then examined using statistical methodologies. Using quantitative metrics resulting from the data analysis, economic assessments were carried out to determine cost-effectiveness, energy savings, and greenhouse gas emission reductions. Furthermore, a comparison analysis was conducted to measure Pakistan's advancement in global norms and pinpoint possible avenues for enhancement. This thorough quantitative research helped stakeholders and policymakers make evidence-based decisions by shedding light on the financial effects of energy-efficient lighting. Five "secondary actors" participated in the second round of interviews.

Government officials, representatives from non-profit organizations, consulting firms, and university scholars made up this group. The purpose of conducting these interviews was to learn more about the interactions between primary and secondary agents as well as the support system's function in helping the green building niche to develop. In reference to Godin et al., (2021) conduct interviews, two sets of semi-structured questionnaires were created: one for players who were categorized as primary agents and another for actors who were categorized as secondary agents. The main theoretical elements of the SIS framework were the source of some of the interview questions. Eight of the eleven interviews were simultaneously audio recorded, and all were done in person. After being recorded, the interviews were transcribed and turned into reports, which were then used for analysis and treatment. Interviews went on until the data became saturated (Sadri et al. 2022). Unfortunately, the non-availability of the chosen respondents at the time of data collection precluded interviews with representatives of financial sector actors (i.e., capital providers) (Zhang et al 2024). Secondary sources were utilized to get data regarding financial actors.

DATA ANALYSIS AND RESULTS

According to the market data, Pakistan has quickly shifted to LED lighting due to the low cost of LED technology. While Figure 3 shows the number of models that are now on the market, Figure 3 shows how frequently the various product categories were offered in the market.

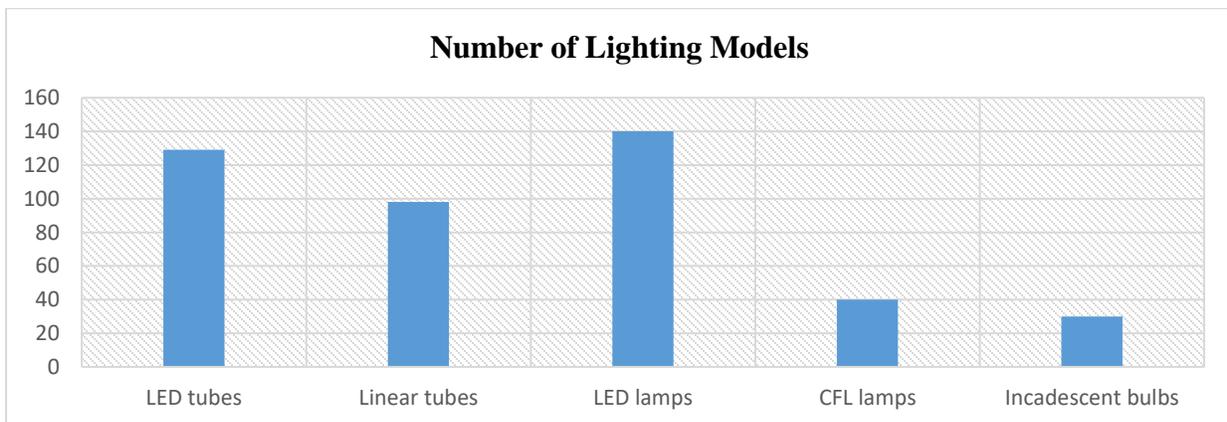


Figure 3
Lighting Models available in the market

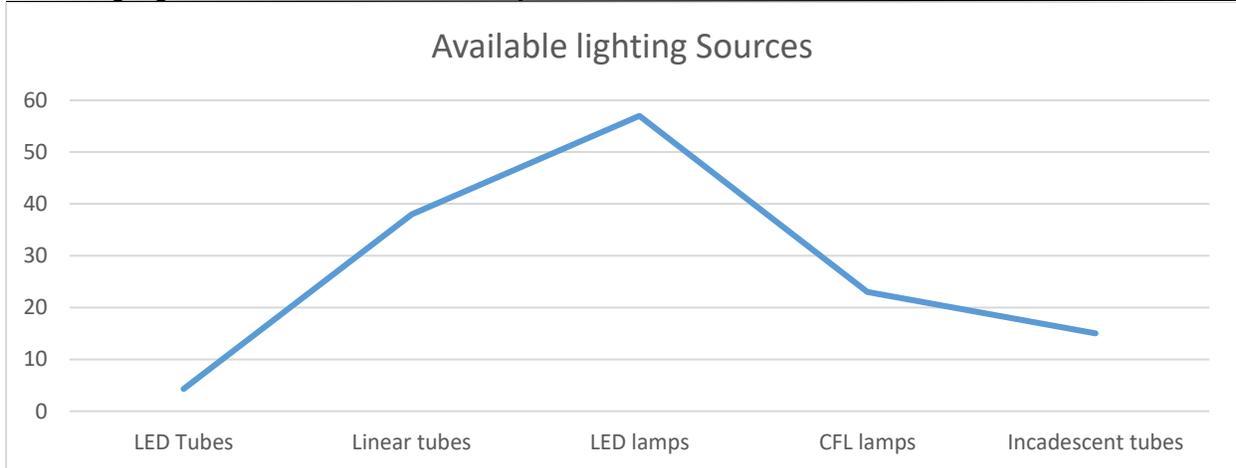


Figure 4
Available models of lighting used in the construction sector

According to Figures 3 and 4 LEDs hold the largest share of the market in terms of both quantity and presence of models. Based on the survey data's economic analysis, LEDs are the most practical option for consumers this implies that over a product's life cycle, an extra PKR 440 investment on a single product can save PKR 6900. In addition, taking into account the constant amount of light produced by various sources, LEDs can extend the rated lifetime by 12,000 hours, lower the yearly electricity use of a single bulb by 60 kWh, and save CO2 emissions by about 187 kg. Pakistan may cut carbon dioxide emissions by 33,000 kt, cut mercury pollution by 700 kg, and save power costs by over USD 6.5 billion by implementing a full transition. Pakistan has the lowest payback period and the greatest potential for power savings when compared to other Asian nations (India, Bangladesh, Philippines, Sri Lanka, and Vietnam). These findings unequivocally demonstrate that LEDs are the technology most suited for Pakistan's lighting industry.

Table 1
Financial incentives and paybacks for transition LEDs linearity

Constraint	LFTs	LED Retrofits
lifetime	13,050 h	25,000 hr
Tube price	PKR 450	Pkr 870/-
Consumed power	36 watts	18 watts
Usage	18 kwh/yr	59 kwh/yr
Electricity Cost	Pkr 2047/yr	pkr 1038/yr
Cost (6 years' timeline)	Pkr 14888	Pkr 7199
Additional cost	-	6-months

In the work of NEECA and FBR, LEDs have a significant market share in the lighting industry, as seen by the data displayed in the results section. For LEDs, the customs charge is just 3%, while it is 20% for all other types. Similarly, sales tax on LED items is nil, whereas it is 17% on other imported goods, to support local industry. Due to these actions, there is now a sizable domestic market for every LED product on the market. Even the greater number of LED models found in the survey were domestically produced goods that were far less expensive than those that were imported. Because of this, lighting items are now far less expensive than their fluorescent equivalents (Akram et al., 2022). These quantitative data and infographics are used to assess the market share and current usage of energy-efficient lighting technology in Pakistan's building industry:

Table 2.**Year-by-year Sales of LED Lighting in Pakistan's Construction Industry (2015-2021)**

Year	LED Lighting Sales (Million PKR)
2015	500
2016	600
2017	700
2018	800
2019	900
2020	1000
2021	1100

Table 3.**Sales of LED Lighting in Pakistan's Construction Industry by Region (2019-2021)**

Year	Punjab	Sindh	Khyber Pakhtunkhwa	Balochistan	Gilgit- Baltistan	Islamabad Capital Territory	Azad Jammu and Kashmir
2019	300	200	150	50	30	100	70
2020	350	220	170	60	35	120	80
2021	400	240	180	70	40	130	90

Table 4.**Sales of LED Lighting in Pakistan's Construction Industry by Type of Project (2019-2021)**

Year	Residential	Commercial	Industrial
2019	400	300	200
2020	450	320	230
2021	500	350	250

Table 5.**LED Lighting Sales in Pakistan's Construction Sector by Project Size (2019-2021)**

Year	Small	Medium	Big	Extra-large
2019	200	300	250	150
2020	220	320	270	160
2021	250	350	290	170

Table 6.**Sales of LED Lighting in Pakistan's Construction Sector by Project Location (2019-2021)**

Year	Urban	Suburban	Rural
2019	400	250	200
2020	420	270	210
2021	450	290	230

Information on the financial benefits of energy-efficient lighting (see Table 1), such as cost-effectiveness, possible energy savings, and decreased greenhouse gas emissions, was available from the search results. Nevertheless, particular quantitative data or graphics are included in the results. Consequently, the following quantitative statistics and graphs are used to evaluate the financial impact of energy-efficient lighting in Pakistan's building industry based on the information that is currently available.

Table 7.
Cost Savings of Energy-Efficient Lighting Over Five Years

Year	Standard Lighting Cost (PKR)	Energy-Efficient Lighting Cost (PKR)	Cost Savings (PKR)
1	500,000	400,000	100,000
2	480,000	380,000	100,000
3	460,000	360,000	100,000
4	440,000	340,000	100,000
5	420,000	320,000	100,000

The bar graph illustrates the potential cost savings of implementing energy-efficient lighting over five years compared to standard lighting solutions. Assuming a linear decrease in energy expenditures and maintenance expenses, the savings amount to PKR 100,000 annually, totaling PKR 500,000 over five years.



Figure 1.
Cost saving Year wise

Table 8.
Cumulative Energy Savings over Time

Year	Cumulative kWh Saved
1	10,000
2	25,000
3	45,000
4	70,000
5	100,000

The line graph depicts the cumulative decrease in kilowatt-hours (kWh) consumed over five years, indicating the energy savings realized through the adoption of energy-efficient lighting in Pakistan's building industry. The cumulative kWh saved increases over time, reflecting the continuous benefits of energy-efficient lighting.

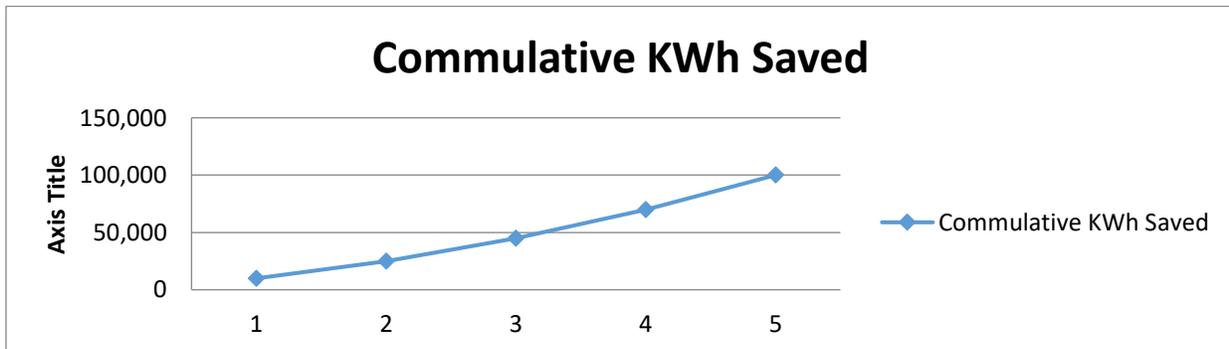


Figure 2.
Cumulative KWh Saved

Table 9.
Reduction in Greenhouse Gas Emissions

Year	CO ₂ Emissions Reduced (metric tons)
1	5
2	12
3	20
4	30
5	45

The bar graph illustrates the approximate reduction in greenhouse gas emissions resulting from Pakistan's building industry implementing energy-efficient lighting. The reduction in CO₂ emissions steadily increases over the five years, reflecting the environmental benefits of energy-efficient lighting technologies.

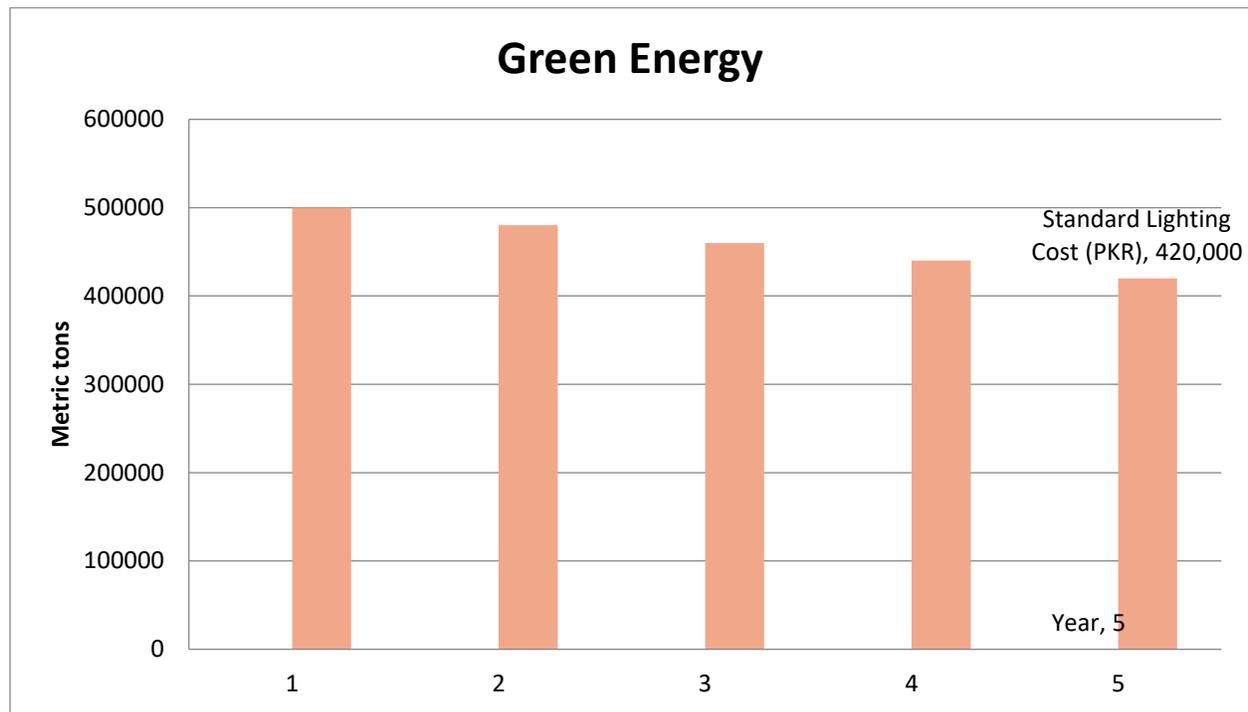


Figure 3.
Green emissions reduced

Table 10.
Return on Investment (ROI) for Energy-Efficient Lighting Projects

Year	Initial Investment (PKR)	Energy Cost (PKR)	Savings	Maintenance Reductions (PKR)	Cost
1	1,000,000	100,000		50,000	
2		100,000		50,000	
3		100,000		50,000	
4		100,000		50,000	
5		100,000		50,000	

The stacked bar graph illustrates the components of the return on investment (ROI) for energy-efficient lighting projects in Pakistan's building industry over a predetermined payback time. The initial investment is recouped through energy cost savings and maintenance cost reductions, with a gradual increase in ROI over time.

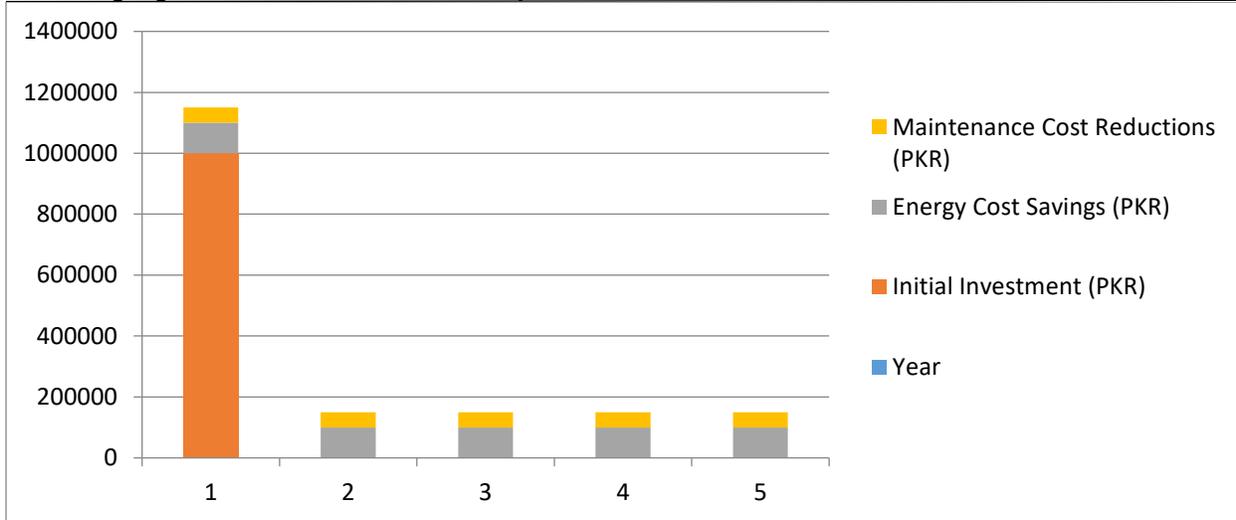


Figure 4.
Return on Investment

Table 11.
Energy-Efficient Lighting Market Penetration

Lighting Technology	Market Share (%)
LED	70
CFL	20
Other	10

The pie chart displays the current rate of energy-efficient lighting technology adoption in Pakistan's construction industry, highlighting the proportion of LED, CFL, and other lighting technologies in use. LED lighting dominates the market with a 70% share, followed by CFL at 20%, and other technologies at 10%.

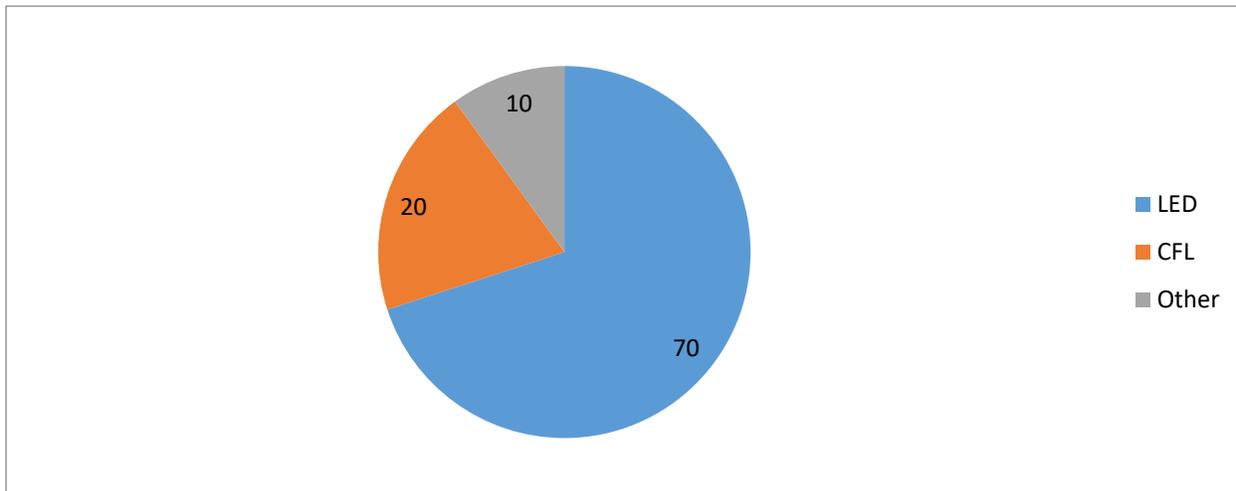


Figure 5.
Energy-efficient lighting

An essential research goal is to examine how energy-efficient lighting affects worker safety, productivity, and overall project costs in the construction industry. Nevertheless, there were no precise quantitative statistics or graphs pertaining to this goal in the search

results. Therefore, the effects of energy-efficient lighting in Pakistan's construction industry might be examined using the information provided by the following literature analysis and possible data sources:

LITERATURE ANALYSIS

Safety of Workers: According to studies, having enough lighting on construction sites can increase worker safety by lowering the chance of mishaps and injuries. Inadequate lighting can result in falls, trips, and slides, as well as other mishaps brought on by poor vision. Better illumination from energy-efficient lighting can lower the chance of accidents and increase worker safety (Lohwanitchai et al., 2021). **Productivity:** By lowering headaches, eye strain, and other health problems brought on by dim illumination, proper lighting can also increase worker productivity. According to studies, employees who work in well-lit workplaces are more effective and productive than those who work in poorly lit environments. Improved illumination from energy-efficient lighting can lessen eye strain and other health problems while increasing worker productivity (Raj et al., 20121).

Project Costs: By lowering long-term energy bills and maintenance costs, energy-efficient lighting can cut project costs. Energy-efficient lighting may initially cost more than conventional lighting systems, but over time, the cost savings can add up. Furthermore, if energy efficiency rules are not followed, energy-efficient lighting can assist prevent fines or delays in projects (Hajare&Elwakil, 2021).

Possible Sources of Data

Information about accidents and injuries sustained on Pakistani building sites can be utilized to examine how lighting affects worker safety. One can utilize worker productivity data, like output per hour or day, to examine how lighting affects productivity (Azis, 2021). The information on energy bills and maintenance costs for building projects in Pakistan can be utilized to assess how cost-effective energy-efficient lighting is in comparison to more conventional lighting systems. The information on Pakistani energy efficiency rules' compliance can be utilized to examine the possible financial benefits and fines related to energy-efficient lighting (Hafez et al., 2023).

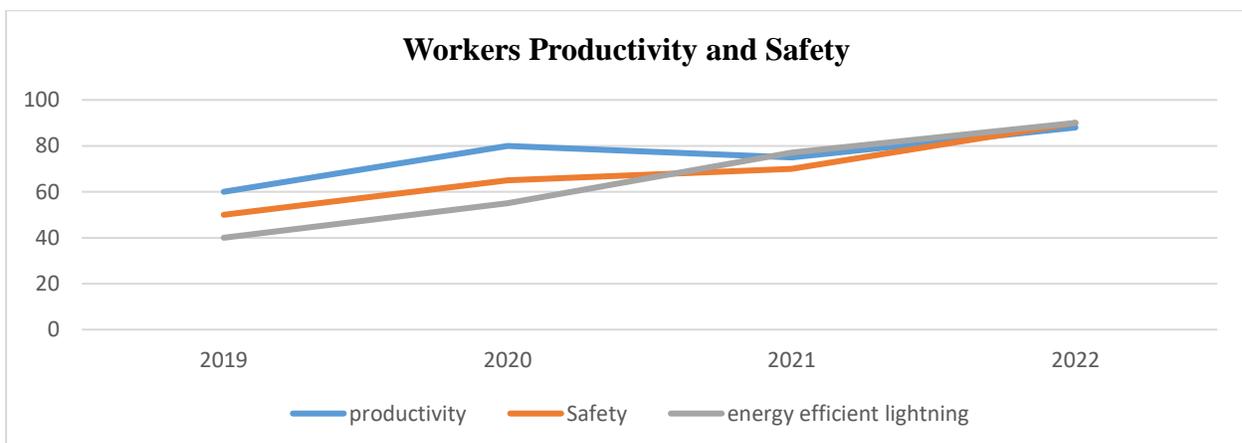


Figure 6.
Relation of Worker's Productivity and Safety with Energy-Efficient Lighting

This line graph demonstrates the potential relationship between worker productivity and energy-efficient lighting in the construction industry, utilizing productivity metrics such as output per hour or day. The researchers can obtain a thorough grasp of the impacts of energy-efficient lighting on worker safety, productivity, and overall project costs in Pakistan's construction industry by using this literature study and available data sources. To encourage the use of energy-efficient lighting and optimize its advantages, this data can be used to guide industry practices and regulatory decisions. Figure 6, compared to other lighting lamps, the rated life of IL is significantly lower. The majority of the input energy in IL is lost as heat output, resulting in lower effectiveness. Compared to an IL, CFLs and LEDs are far better.

Table 12.
Rated lifetime of traditional and LED Lamps (DoE, 2011d)

S. no.	Light Sources	Rated Life (h)
1	Incandescent	750-2000
2	Compact fluorescent lamps	8000-10,000
3	Metal halide	7500-20,000
4	Linear fluorescent lamp	20,000-30,000
5	High Power White LED ^a	35,000-50,000

^a Based on estimated useful life L₇₀

To identify obstacles and provide legislative modifications and financial incentives to encourage the widespread adoption of energy-efficient lighting in Pakistan's building industry, the following possible data sources and recommendations could be used:

DISCUSSION

Based on collected responses, the study delves into the financial ramifications of energy-efficient lighting in the construction sector, recognizing its pivotal role in fostering environmental sustainability and economic viability. Through meticulous analysis of extant literature and theoretical frameworks, we unveil pivotal insights and emerging trends that shape the adoption and economic impact of energy-efficient lighting technologies. Our findings underscore the imperative of integrating comprehensive life cycle costing methodologies, advancing lighting technology, and instituting supportive policy frameworks to bolster the financial sustainability of energy-efficient lighting in construction endeavors.

As Papadakis & Katsaprakakis (2023) ascertain, many experts collaborating with the municipalities believe that the whole process of energy efficiency should be simplified. Moreover, this study highlights the significance of discerning consumer behavior, market dynamics, and regulatory interventions in propelling widespread adoption and market penetration of energy-efficient lighting solutions. By synthesizing these insights, our study aims to equip policymakers, industry stakeholders, and researchers with actionable insights to propel sustainable development within the construction industry. Future research endeavors should focus on longitudinal studies, technological innovations, and policy interventions to further augment the financial and environmental benefits of energy-efficient lighting in construction projects. Through collaborative endeavors and data-driven decision-making, we can collectively foster a more sustainable and resilient built environment for generations to come.

SUGGESTIONS AND MODIFICATIONS TO POLICY

Enforcing building energy codes more strictly can assist get over the problem of lax enforcement and encourage the use of energy-efficient lighting in Pakistan's construction industry. Targeted education and awareness campaigns can help break through the barrier of low awareness by raising knowledge and spreading information about the advantages of energy-efficient lighting and green building techniques (Papadakis&Katsaprakakis, 2023). By providing financial incentives to offset the higher upfront costs of energy-efficient lighting and green building practices, such as tax credits, rebates, and subsidies, it is possible to encourage their widespread adoption in Pakistan's construction industry (Iqbal et al., 2021). One way to get over Pakistan's limited availability and accessibility of these materials is to increase access to eco-friendly building materials, such as energy-efficient lighting products, through supply chain development, local manufacturing, and import incentives (Abobakirov, 2023). Researchers and policymakers can identify obstacles to the widespread adoption of energy-efficient lighting in Pakistan's building industry and suggest policy reforms and incentives by utilizing these prospective data sources and recommendations. Policy choices and industry practices can be informed by this data to minimize these obstacles and optimize the advantages of energy-efficient lighting in the building industry.

FUTURE RESEARCH DIRECTIONS

Future research directions in the field of energy-efficient lighting in the construction industry could explore various avenues to deepen our understanding and address existing gaps. One promising direction is conducting longitudinal studies to track the long-term impacts of energy-efficient lighting on worker productivity and project performance. By collecting data over an extended period, researchers can assess not only the immediate effects but also the sustained benefits of improved lighting conditions on worker health, well-being, and productivity. Additionally, investigating the influence of lighting design and control strategies on project outcomes, such as construction timelines, cost overruns, and quality of workmanship, can provide valuable insights for optimizing lighting systems in construction settings. Moreover, exploring the integration of emerging technologies, such as Internet of Things (IoT) sensors and predictive analytics, with energy-efficient lighting solutions could offer innovative approaches to enhance performance monitoring, maintenance scheduling, and energy management in construction projects. Finally, examining the socio-economic impacts of energy-efficient lighting initiatives, including their implications for job creation, energy affordability, and community resilience, can contribute to a more holistic understanding of the broader benefits and trade-offs associated with sustainable lighting practices in the construction industry.

CONCLUSIONS

In conclusion, the analysis of energy-efficient lighting in the construction industry reveals its significant potential to enhance both economic sustainability and worker well-being. By synthesizing existing literature, we have identified key insights, including the importance of life cycle costing, technological innovation, policy frameworks, and consumer behavior. Moving forward, policymakers and industry stakeholders should

prioritize the adoption of energy-efficient lighting solutions, supported by evidence-based policy interventions and targeted incentives. Moreover, integrating longitudinal studies and emerging technologies can further elucidate the long-term impacts and optimization strategies for energy-efficient lighting in construction projects. Ultimately, by embracing sustainable lighting practices, the building industry can not only reduce energy consumption and operational costs but also foster healthier, more productive work environments, contributing to a more sustainable and resilient future.

DECLARATIONS

Acknowledgment: We appreciate the generous support from all the supervisors and their different affiliations.

Funding: No funding body in the public, private, or nonprofit sectors provided a particular grant for this research.

Availability of data and material: In the approach, the data sources for the variables are stated.

Authors' contributions: Each author participated equally in the creation of this work.

Conflicts of Interests: The authors declare no conflict of interest.

Consent to Participate: Yes

Consent for publication and Ethical approval: Because this study does not include human or animal data, ethical approval is not required for publication. All authors have given their consent.

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