DEVELOPMENT OF A STRATEGIC FRAMEWORK EMPOWERING SRI LANKAN HOTELS TOWARDS NET ZERO EMISSIONS THROUGH SUSTAINABLE RETROFITTING

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Declaration of the Candidate and the Supervisor

I declare that this is my own work and this dissertation does not incorporate without acknowledgement any material previously submitted for a Degree or Diploma in any other University or institute of higher learning and to the best of my knowledge and belief it does not contain any material previously published or written by another person except where the acknowledgement is made in the text.

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Abstract

This thesis explores sustainable retrofitting strategies for small to medium-sized resort-type hotels in Sri Lanka, aiming to achieve decarbonization goals and enhance sustainability. The primary objective is to develop practical guidelines that ensure operational efficiency, focusing on improving energy, water, and resource consumption performance. The research employs a mixed-methods approach, combining both qualitative and quantitative analyses to assess the baseline performance of resort-type hotels in Sri Lanka and identify effective retrofitting strategies. Key findings of the study indicate that over 80% of greenhouse gas (GHG) emissions in these hotels are attributable to energy consumption, underscoring the critical need for energy performance enhancement. Although water and waste contribute less to GHG emissions, their impact on operational costs is significant. Performance metrics such as energy consumption per occupied room, water usage, waste generation, and GHG emissions per occupied room were utilized to evaluate hotel performance. Improving these metrics is essential for cost reduction and minimizing GHG emissions, thereby boosting the overall sustainability profile and attracting eco-conscious guests. The research also identified decision-making challenges faced by hotel stakeholders when implementing new strategies. Using the Analytical Hierarchy Process (AHP), the study pinpointed key decision criteria: annual emissions saving, adaptability, initial investment, payback period, maintenance requirements, and technical complexity. A total of 30 feasible and effective retrofitting techniques were assessed, providing a comprehensive set of options for hotel operators. The implications of this research are significant for the hospitality industry, particularly for resource-limited small to medium-sized hotels. The developed guidelines and framework enable these hotels to systematically evaluate their emissions using a GHG Emissions Calculator and make informed decisions on retrofitting strategies. The framework's inclusion of local benchmarks, based on sample analysis, resolves the challenge of informed decision-making for sustainable retrofits. However, this study focuses exclusively on small to medium-sized hotels in Sri Lanka, potentially limiting the generalizability of the results. The research timeframe also restricted the exploration of long-term impacts of sustainable retrofits.

Future research should address these limitations by expanding the scope to include larger hotels, diverse geographic regions, and a broader range of retrofitting strategies, including those involving the latest technologies. Additionally, understanding the behavioral changes of guests and staff regarding sustainable practices will further inform effective decision-making. In conclusion, this thesis provides a robust framework and practical guidelines for sustainable retrofitting in small to medium-sized resort-type hotels, highlighting the potential for significant environmental and economic benefits. By adopting these strategies, hotels can enhance their sustainability profile, reduce operational costs, and contribute to global decarbonization efforts.

Key Words: Sustainable Retrofitting, Decision Support, Sri Lankan Hotels, Operational Optimization, Analytical Hierarchy Process (AHP), Strategic Framework

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CHAPTER 1

1. Introduction

1.1. Research Background

Climate Change has become one of the biggest environmental challenges faced by the present generation. Due to the continuous a anthropogenic greenhouse gas emissions, and global warming has increased losing the balance of the climate. The current atmospheric Carbon Dioxide level has reached up to 420 ppm, which is a huge deviation from the pre-industrial level and now the planet Earth is in a climate emergency. Whole sector decarbonization is the only way to mitigate the impact of Climate Change as per the Paris Agreement. Accordingly, as shown in Figure 1-1, there is a global target to halve the emissions from the built environment by 2030 and fully decarbonize it by 2050 to limit global warming at 1.5˚C compared to pre-industrial levels. Nationally Determined Contributions (NDCs) articulate each country's efforts to reduce national emissions and adapt to the impacts of climate change being the heart of the 2015 Paris Agreement. [1]

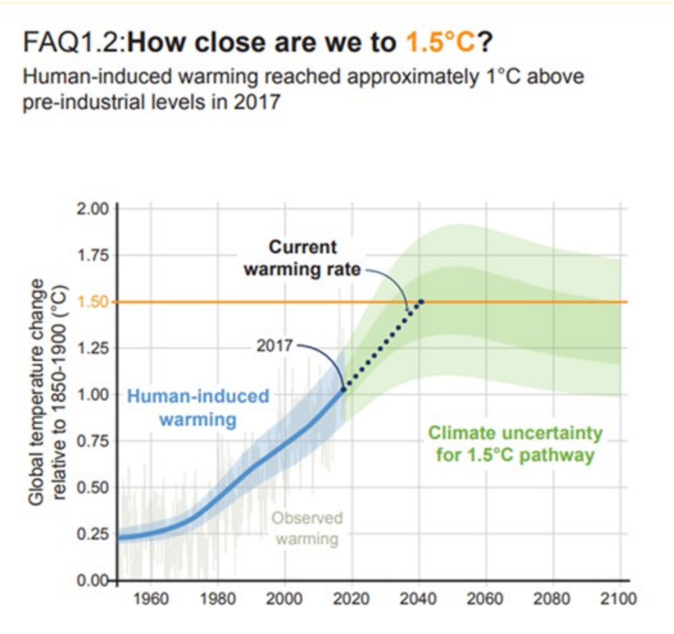

Figure 1-1: IPCC Special Report on Global Warming of 1.5°C

2023 September marking an unprecedented milestone as the hottest month ever recorded globally, it underscores the accelerating impact of climate change. The amplification of extreme weather events, shifts in climate patterns and rising global temperatures have urged immediate and comprehensive strategies to address this pressing global concern.

The building sector being a significant contributor to environmental deprivation, with considerations rising over energy, water, and resource consumption, the built environment is critical to achieving a more sustainable future.

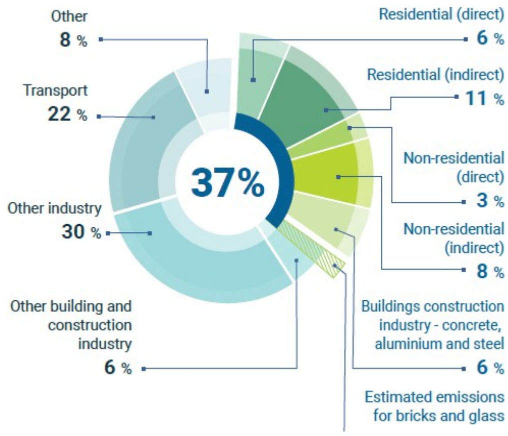

Figure 1-2: Share of buildings in global energy and process emissions in 2021[2]

Buildings have become a major culprit of Climate Change being a significant contributor to global greenhouse gas emissions due to the huge fossil fuel usage associated during their lifecycle. As per the United Nations Environment Program's Building Construction Global Status Report 2022 highlights, 75% of annual global greenhouse emissions from the built environment contributing nearly 37% from the building sector itself as shown in Figure 1-2. [2] Also, buildings account for 34% of global final energy consumption (Refer to Figure 1-3) since buildings are a major consumer of energy as highlighted in the International Energy Agency's 2019 report. [3] Among the reasons for this unnecessary consumption, major factors are; inefficient building designs, poor and energy inefficient equipment as well as weak insulation of building envelope. As solutions, there are many strategies that can be adopted in buildings to improve the energy efficiency including; renewable energy integration, low carbon technologies, integrating passive design features, and upgrading equipment. Those practices will substantially reduce energy consumption, leading to a reduced carbon footprint and ultimately contribute to mitigating climate change with a low-carbon future.

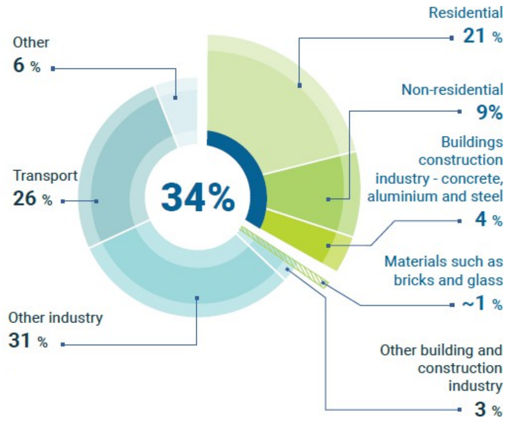

Figure 1-3:Share of buildings in total final energy consumptions in 2021 [2]

Buildings also play a significant role in water consumption while water scarcity is another pressing global issue. Out of the many building types, residential and commercial buildings contribute substantially to this overall water demand. As the United Nations Environment Program reveals, buildings consume nearly 13% of the world's freshwater [2]. Inefficient water management practices, behavioral patterns and unnecessary water leakages are major reasons behind the unsustainable water practices in buildings. Addressing water management, through implementing policies, monitoring and eliminating water leakages, upgrading water fixtures to water efficient ones, rainwater harvesting, etc. will support reducing water consumption, especially potable water consumption.

Resource depletion is another global issue where buildings also contribute to resource consumption, accounting for nearly half of the annual global solid waste generation. As per UNEP 2022 report, 40% of the world's total waste is from the construction and demolition sector. In the operation stage of the buildings, inefficient waste management practices further compound the problem which leads to higher waste output directed to landfills. Addressing waste generation and proper waste management and disposal through circular economy principles will mitigate this matter improving the sustainable performance of the buildings. [4]

Also, buildings are the habitats of humanity where 90% of the time they stay indoors. Thus, it shapes the quality of human life , which makes it essential to enhance the sustainability and the sustainable performance of buildings [5]. A holistic sustainability approach that provides a balanced commitment to economic, environmental, and social bottom lines, will be important in improving the sustainable performance of the building. This approach aims to reduce the environmental impact of buildings while promoting economic, social, and environmental sustainability. However, despite the increasing interest and efforts towards climate resilience, the need for a comprehensive assessment framework that can guide the selection of effective strategies and support decision-making in sustainable adaptation strategies has become a priority.

1.1.1. Climate Resilience, Adaptation, Mitigation

Climate resilience denotes a system's ability to withstand and recover from the impacts of climate change while retaining essential functions. It encompasses strategies to mitigate disruption and maintain stability in the face of changing environmental conditions. On the other hand, adaptation refers to the proactive adjustments made to address the effects of these changing conditions. It involves implementing measures to reduce vulnerability and enhance capacity, ensuring sustainable operations. In contrast, mitigation efforts are aimed at reducing or prevent the emission of greenhouse gases, addressing the fundamental causes of climate change. Both adaptation and mitigation strategies are vital in addressing the challenges posed by a continuously changing climate, aiming to ensure not only resilience but also a sustainable and robust response to environmental fluctuations.

Building retrofitting plays a major role in addressing the challenges caused by climate change. It also enhances the resilience of the built environment. By engaging the retrofitting strategies in energy saving, water saving fixtures and climate resilient infrastructure, it supports mitigating the adverse impacts of climate related risks and adapting to the changing environmental conditions. For instance, the impact of heatwaves and urban heat island effect is reduced through retrofitting strategies such as cool roofs, green roofs and improved insulation. As another example, the heavy water intake can be collected and stored for further use, which will minimize the risk of flooding.

1.1.2. Sri Lanka in the phase of Climate Change

Sri Lanka located in the Indian Ocean as an Island, features a tropical climate characterized by distinct wet and dry seasons. As a result of the geographical diversity, ranging from coastal plains to mountainous terrain, there are varied microclimates across the island. Sri Lanka's climate is mostly and strongly influenced by the southwest and northeast monsoons, which bring heavy rainfall to different regions at varying times of the year. [6] The southwestern monsoon usually affects the

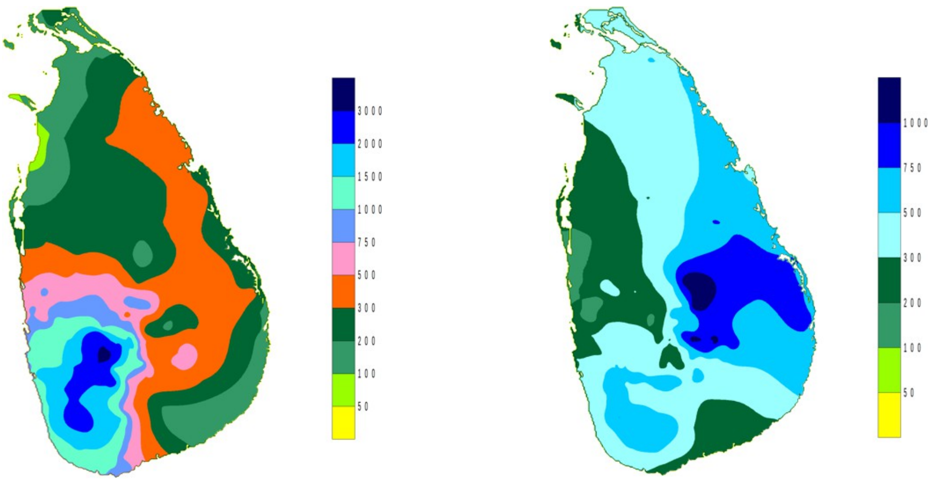

Figure 1-4: Climate pattern - Sri Lanka

southwestern and central regions from May to September, bringing extensive rainfall. Contrary, the northeastern monsoon influences the eastern and northern regions from December to February, delivering rainfall to those areas. These seasonal monsoons form the backbone of the country's climate pattern, supporting agricultural activities, power generation and many other economic, and non-economic activities based on water resources.

However, despite the essential adaptability to these seasonal variations, Sri Lanka also faces challenges associated with climate change. Over recent years, the country has experienced noticeable shifts in its climate patterns, leading to more frequent and intense weather events. These changes include rising temperatures, changed rainfall patterns, and an increased frequency of extreme weather occurrences such as floods, droughts, and landslides.[7]

Sri Lanka's vulnerability to climate change is highlighted by several factors, including its coastal geography, agriculture-based culture, and the density of its population in vulnerable areas. Also, Sri Lanka’s high temperatures, unique and complex hydrological regime, and exposure to extreme climate events make it highly vulnerable to climate change. [8] Rising sea levels threaten coastal communities and infrastructure, specifically in low-lying areas, resulting in increased risks of erosion and flooding. Changes in rainfall patterns interrupt agricultural cycles, affecting food security and livelihoods. The augmented frequency and intensity of extreme weather events pose threats to public safety, infrastructure, and ultimately the economy. The Sri Lankan government has acknowledged the urgency of addressing climate change related challenges. Several initiatives like the National Climate Change Adaptation Strategy have been established to enhance the country's resilience towards reducing vulnerabilities to climate change impacts. Moreover, Sri Lanka's Nationally Determined Contributions (NDCs) under the Paris Agreement emphasize the nation's commitment to mitigate greenhouse gas emissions and foster sustainability. These steps taken to address climate change challenges reflect the country's commitment to building resilience and mitigating adverse impacts. It is highly important to maintain continued efforts and international cooperation in combating the multifaceted challenges posed by climate change in Sri Lanka. Adaptation strategies, effective mitigation measures and sustainable development practices are imperative to safeguard the nation's environment, economy, and society against the growing threats of climate change.

1.1.3. Climate Adaptation Plan for Sri Lanka

In recent years, Sri Lanka has been challenged with a surge in climate-related disasters, including damaging floods and prolonged droughts. These occurrences have disclosed the country's vulnerability to the changing climate and emphasize the immediate need for robust and adaptable solutions to mitigate potential future risks. Acknowledging the critical role of adaptation strategies, Sri Lanka has embarked on an ambitious National adaptation plan for 2016-2025, targeting highly vulnerable sectors within the country. Accordingly, Sri Lanka's National Adaptation Plan identifies agriculture, fisheries, water, human health, coastal and marine regions, ecosystems, biodiversity, infrastructure, and human settlements as the most sensitive sectors facing the adverse impacts of climate change. Providing a strategic plan, acts as a catalyst for engaging all stakeholders in crafting policies, fostering partnerships, enhancing institutional structures, securing resources, driving technological advancements and their dissemination, raising awareness, and empowering capacities. These collective efforts aim to fortify the resilience of vulnerable communities, regions, and sectors throughout the country, highlighting the need for tailor-made solutions to safeguard vulnerable areas [9]. As per the National Adaptation Plan, the hospitality sector has been identified as one of the most vulnerable sectors in Sri Lanka that faces unique challenges attributed to climate change, such as threats to tourism-related infrastructure, distorted traveler behavior patterns, and impacts on natural attractions. These challenges demand specific adaptation strategies within the sector to ensure sustainable and resilient tourism practices and safeguard the industry's future.

1.1.4. Role of Building Retrofitting as an Adaptation Strategy

The tourism and recreation section in the National Adaptation Plan highlights the need to improve the climate resilience of tourism facilities through building retrofitting to increase the preparedness of tourism and recreation operations to extreme weather conditions such as heat waves, extreme rain events and floods. Building retrofitting is a crucial strategy to enhance climate adaptability achieving net zero emissions specially in the context of Sri Lankan hotels. Previous studies have shown that retrofitting existing buildings is a cost-effective approach that helps mitigate environmental impacts by improving energy performance and reducing Greenhouse gas emissions [10]. This process is inclusive of tailoring retrofitting measures to different climatic conditions in different zones in Sri Lanka ensuring optimal performance. Building envelop upgrades for enhanced thermal performance, selecting climate resilient materials and improving HVAC system while improving and maintaining indoor air quality are some critical components of this strategy. Furthermore, incorporating disaster resilience into these retrofitting strategies will safeguard buildings against growing threats of extreme weather events such as heavy rains, floods and storms etc. If the national policies and standards are also aligned with regional climate needs while fostering continuous research and innovation in retrofitting techniques, the pathway towards Net Zero Emissions will be much easier for Sri Lankan Hotels. This is a minor step similar to that proposing a strategic framework that leverages the principles to empower Sri Lankan hotels towards Net Zero through sustainable retrofitting.

1.1.5. Hospitality Sector and Climate Change

As a vital component of global infrastructure, the hotel sector faces growing challenges due to the escalating impacts of climate change. According to recent statistics by the UN World Tourism Organization, the Tourism and Hospitality industry significantly contributes to global greenhouse gas emissions which is estimated to be around 8% [11]. Climate Change related impacts such as rising sea levels, extreme weather events, and temperature fluctuations directly impact the coastal regions where considerable components of hotels reside. The continuous growth of tourist arrivals also highlights the significance of the tourism sector for the economic growth in Sri Lanka. However, the climate change vulnerability of these hotels in the coastal region poses a significant risk to the nation's tourism industry. As these challenges endure, it becomes crucial to develop adaptive strategies to strengthen the resilience of hotel infrastructures, operations, and policies in facing increasingly unpredictable environmental conditions, thereby upholding this essential economic sector.

1.1.6. Importance of Sustainability and Environmental Responsibility in the Hospitality Sector

The tourism industry, significantly depending on natural resources and being susceptible to climate change underscores the urgency for adaptation strategies. Rising sea levels and extreme weather events threaten coastal hotels, while changing weather patterns affect tourist behaviors and preferences. For instance, a study conducted in 2018 reported that around 82% of surveyed tourists in Sri Lanka contemplated environmental sustainability as an important factor in their travel decisions. [12] Therefore, it's a proven fact that climate adaptation within the hospitality sector is crucial for ensuring the resilience and sustainability of the industry. As global climate changes continue to impact travel patterns and environmental conditions, implementation of adaptive measures, such as sustainable infrastructure development, renewable energy integration, water and waste management, and community-based resilience programs, become predominant. The ND-GAIN Index demonstrates a country's vulnerability to climate change and other global challenges in combination with its readiness to improve resilience. It focuses on helping businesses and the public sector to better prioritize investments for a more efficient response to the immediate global challenges ahead. As a result of a combination of political, geographic, and social factors, Sri Lanka is recognized as vulnerable to climate change impacts, ranked 104th out of 181 countries in the 2021 ND-GAIN Index [8]. Therefore, the integration of retrofitting strategies as climate adaptation actions in the hospitality sector in Sri Lanka will be a proactive step to safeguard the industry's future. In this context, investing in climate adaptation strategies in the hospitality sector goes beyond business resilience, signifying a commitment to sustainable tourism practices, ensuring the preservation of natural resources, safeguarding local communities, and aligning with global efforts to mitigate climate change impacts. Ultimately, the implementation of effective adaptation measures within the hospitality sector in Sri Lanka stands as a cornerstone for a sustainable, resilient, and environmentally conscious tourism industry.

1.2. Problem Statement

Addressing the challenges of Net Zero emissions, Sri Lanka is implementing various sustainable strategies across different industries, with a special focus on the hospitality sector, which contributes nearly 3% of GDP (which was 10% in 2019 before the pandemic) [13]. Being a top contributor to the national economy, the hospitality sector consumes an extensive amount of energy with high greenhouse gas (GHG) emissions. Thus, it is crucial to prioritize sustainable practices in hotels and resorts to achieve the country's environmental goals. However, Sri Lankan hotels have faced significant challenges in implementing sustainable practices mitigating carbon emissions.

Key challenges include:

- The lack of benchmarks for emissions and other environmental parameters specific to Sri Lankan hotels,
- Hotel operators often lack the knowledge to select the optimal retrofitting solutions through a multifaceted decision-making process necessarily looking at the lifecycle perspectives,

Amidst the urgency imposed by global sustainability targets, the absence of a tailored framework exacerbates these challenges, hindering the effective implementation of climate resilient and net zero emission retrofitting strategies. To fill this gap, it is necessary to have a tailored plan that provides actionable guidelines for sustainable retrofitting strategies addressing the unique climatic conditions and operational challenges as well as offering practical solutions for reducing greenhouse gas emissions in the Sri Lankan Hospitality sector. While enhancing climate change resilience it will also ensure operational efficiency and guest satisfaction. Therefore, this research aims to address these critical gaps by developing a strategic framework designed for the sustainable retrofitting of Sri Lankan hotels. This framework will empower hotel operators to select, evaluate and implement effective carbon reduction strategies. It will facilitate the transition towards net zero emissions ensuring Sri

Lankan hotels to meet global sustainability benchmarks and maintain their competitiveness in the increasing eco-conscious tourism industry.

1.3. Aims and Objectives

The aim of this research is to support the Sri Lankan hotel sector to achieve Net Zero emissions through sustainable retrofitting measures.

The following objectives were guided towards achieving the aim of this research.

- To develop a Carbon Emission Calculation Tool tailored for Sri Lankan hotels
- To identify the baseline emissions and existing sustainable retrofitting strategies in Sri Lankan hotels
- To assess the economic viability and environmental impact of the identified retrofitting measures
- To formulate a strategic framework to support the implementation of sustainable retrofits to achieve Net Zero Targets for hotels in Sri Lanka

1.4. Significance of the Study

Along the way towards net zero hotels, Sri Lankan hotel sector is facing difficulty in selecting the optimum solutions to improve their performance. Addressing all the challenges mentioned in the previous section, this study focuses on introducing a tailored solution for hotel industry in Sri Lanka. The importance of this study can be explained in different key points which are elaborated below.

1.5. Systematic Decision Making

This framework provides a structured approach to evaluate each retrofit option ensuring the decisions are made based on clear criteria and priorities. Lifecycle thinking is embedded in the evaluation process. This systematic process enables hotels to assess the potential impact of each retrofit option in terms of cost effectiveness, feasibility and emission reduction etc. Since this adopts a data driven approach hotels can make informed decisions that are aligned with their sustainability goals and financial objectives.

- Transparency and Accountability

Using a structured framework improves transparency and accountability in decision making process related to sustainability initiatives. Hotels are enabled to communicate clearly to their stakeholders on how they have evaluated and prioritized retrofit options. This transparency builds trust and credibility demonstrating the hotel's commitment towards sustainability and responsible business practices.

- Maximize Impact

Since this framework helps hotels to identify and prioritize retrofit strategies with the highest potential for emission reduction and cost saving, focusing on the strategies that can deliver the highest environmental and financial benefits, they can maximize the impact on their sustainability efforts. Specially this approach ensures that resources are allocated efficiently leading to meaningful reductions in carbon emissions and operational costs.

- Adaptability to Different Needs

One of the key strengths of this framework is its adaptability to the diverse needs of individual hotels since it can be customized to prioritize retrofit options that are most relevant and feasible. It will enable hotels to tailor their sustainable strategies to suit their unique operational requirements and budget constraints.

- Long term - Lifecycle thinking

The criteria such as payback period, Annual savings etc. are considered in the framework to encourage hotels to take either long term or lifecycle perspective of the investment decision. Since it focuses on such long-term impacts rather than focusing on short term gains, this strategic approach to decision making ensures that retrofit solutions deliver benefits over time contributing to the hotel's resilience and competitiveness in the market.

CHAPTER 2

2. Literature Review

2.1. Sustainability in the Hospitality Industry

The hospitality industry is uniquely positioned to create a significant impact on global sustainability efforts in the present world. Since this is a sector that directly interacts with millions of people daily, the transition towards sustainable practices will contribute to environmental conservation enhancing guest experience and operational sustainability. Likewise, sustainability in the hospitality sector refers to the implementation of practices that minimize the environmental, social and economic impacts while enhancing the well-being of the stakeholders, including guests, employees and local community. This sustainable movement results in multi-faceted benefits. When looking at the environmental perspective, hotels can reduce resource consumption, minimize waste generation and lower greenhouse gas emissions through sustainable practices. Since the hospitality industry is a significant consumer of energy (Figure 2-1) and water and it is generating a huge amount of waste, it is important to implement measures that improve energy and water consumption efficiency and reduce waste generation. Likewise, the environmental footprint can be reduced in hotels. From an environmental perspective, sustainable practices in hospitality aim to reduce resource consumption, minimize waste generation, and lower greenhouse gas emissions. Hotels are significant consumers of energy and water, and they generate considerable amounts of waste, including food waste, plastics, and hazardous materials. By implementing energy-efficient technologies, water-saving measures, and

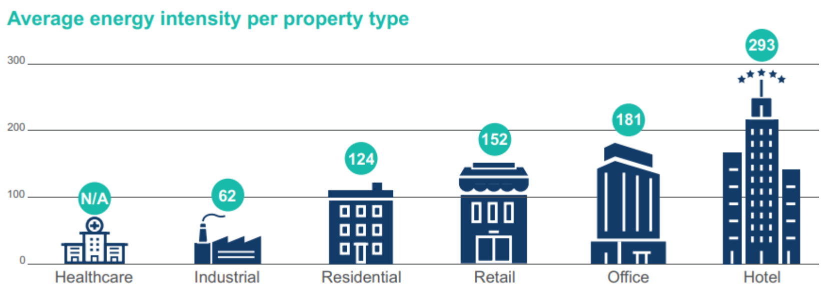

Figure 2-1: Average energy intensity per property type – [63]

waste reduction strategies, hotels can substantially reduce their environmental footprint. [14]

Since improved energy, water and resource efficiency can lead to significant cost savings lowering utility bills and maintenance costs, there is also a positive economic impact [15]. It also enhances the hotel’s reputation and brand value, attracting more and more eco conscious guests. It will also generate a positive economic impact leading to higher occupancy rates and revenues. Sustainable practices can improve guest satisfaction through a healthier and more eco-friendly environment, it enhances social sustainability in the hospitality sector. Likewise, the adoption of different sustainable retrofit strategies in the hospitality sector is crucial for the long-term viability of hotels ensuring its environmentally responsible, economically viable and socially equitable operation.

2.2. Global Sustainability Trends and Initiatives in Hospitality Industry

With the common global commitment to achieve Net Zero by 2050, halving the emissions by 2030, the global hospitality industry has witnessed a growing emphasis on sustainability both by increasing awareness of environmental issues and putting regulatory pressure. [16] Another positive fact is the changing consumer preference on sustainability where the majority of travelers are eco conscious and more concerned on environmentally friendly hotels. As highlighted in the recent Sustainable Travel Report published by Booking.com, as many as 74% of the respondents of the survey conducted using over 33000 travelers in over 35 countries, travelling more sustainably is important to them. 43% of travelers are willing to pay a little more to support certified sustainable travel options [17]. Several global trends and initiatives that highlight this industry’s commitment to sustainability are Green Certifications and labels, GHG Accounting, ESG reporting, Science Based Targets initiative (SBTi), renewable energy integration and carbon trading investments, adopting circular economy principles and green building principles. Therefore, building retrofitting has become an essential area to discover when fulfilling requirements for each trend mentioned above.

- Green Certifications and Labels

Being an important sustainability commitment, green certifications and labels are important to identify truly sustainable destinations. Some of those certifications areas listed in Table 2-1.

Table 2-1: Hotel Certification Schemes related to Sustainability

Certification	Issuance Body
LEED	Green Business Certification Inc. (GBCI)
Green Globe	Green Globe International
Green Key	Foundation for Environmental Education (FEE)
EarthCheck	EarthCheck
Travelife	Travelife for Accommodation, Travelife Ltd
GSTC Certification	Global Sustainable Tourism Council (GSTC)
NSTC Certification	Sri Lanka Tourism Development Authority
GREEN SL Certification	Green Building Council of Sri Lanka

All these certifications provide benchmarks for sustainable practices offering a way to demonstrate the hotels' commitment to sustainability. Most of these certifications involve with detailed energy, water and waste assessments to identify the impact on the environment.

- GHG Accounting

In the pathway to net zero, it has been an essential component to assess the carbon footprint associated with the hotel operation. Global standards of GHG Protocol and ISO14064-1 are the key standards to be followed. Using those standards, few industry-specific frameworks have been developed to assess the carbon footprint of hotel operations. Hotel Carbon Measurement Initiative (HCMI) plays a major role in this regard offering a guided assessment.

- Environmental, Social and Governance (ESG) Framework

Increasing sustainability efforts in the corporate environment has been recognized with this framework which represents a set of standards for an organization's sustainability efforts in all three areas; environmental, Social and Governance. Focusing on low ecological footprints through energy efficiency, water efficiency and waste reduction under the Environmental component and improved welfare to stakeholders under the social component and robust corporate governance structure with ethical and transparent operation under the Governance component ensures a truly sustainable hotel.

- Science Based Targets Initiative (SBTi)

This initiative provides a framework to set GHG Emission reduction targets according to the latest climate science to limit global warming well below 2 degrees above pre-industrial levels, ideally aiming for 1.5 degrees. Through this initiative, hotels are committed to measurable and time-bound goals starting the effort by calculating GHG emissions. SBTi is a collective effort of CDP, the UN Global Compact, the World Resources Institute (WRI) and the World-Wide Fund for Nature (WWF) [18]. Figure 2-2 demonstrates key elements of this SBTi Net Zero Standard.

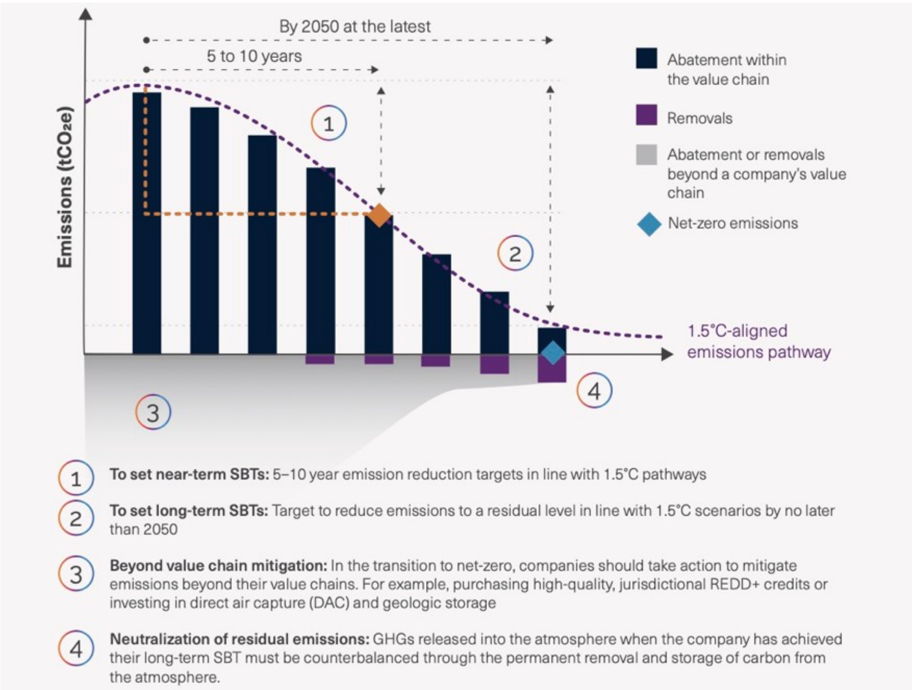

Figure 2-2: Key Elements of SBTi Net Zero Standard [18]

Major hotels such as Accor, Hilton Worldwide, Inter-Continental Hotels Group (IHG), and Marriott International align with SBTi's 1.5 °C trajectory. Hilton aims to cut their environmental footprint by half and double social impact investment by 2030, Marriot has targeted to reduce carbon emission intensity by 30% and water intensity by 15% by 2025 [18].

- Net Zero Carbon Building Commitment

The Net Zero Carbon Building Commitment initiated by the World Green Building Council is to recognize and promote advanced climate leadership action from businesses, organizations, cities and governments toward built environment decarbonization. Through that, it is expected to remove barriers for the implementation of climate actions with the inspiration to take small action. Since the buildings are responsible for 35% of energy consumption, 38% of energy related carbon emissions and 50 % of resource consumption it is important to take bold actions to reduce the impact of the building sector [19].

2.3. Introduction to Carbon Footprint

In the pathway towards Net Zero Hotels through sustainable retrofitting, the initial step of assessing the baseline carbon footprint is essential. A carbon footprint is the total amount of greenhouse gases (GHGs) emitted directly or indirectly by an organization, event, product or individual expressed in equivalent tons of carbon dioxide (tCO_{2e}). Specific to this assessment, the carbon footprint was calculated based on ISO 14064 – 1 standard and GHG Protocol, which provide principles and guidelines for quantifying and reporting an organization's carbon footprint. [20], [21]

The operational control approach was selected to delineate the boundaries of the assessment and it focuses on the emission sources that the organization has direct control over. Table 2-2 highlights the emission sources with direct control, selected under each scope. Figure 2-3 illustrates the overall concept, three scopes and related sources in general organization. This approach ensures a clear and manageable scope for intervention, making it easier to implement and monitor emissions reductions.

Scope 3 emissions are indirect emissions that occur in the value chain of the reporting company. In this context, the supply chain related emissions except for water and waste related emissions were excluded from the study since it aims to directly influence and reduce the most significant sources of GHG emissions that can be managed through retrofitting measures.

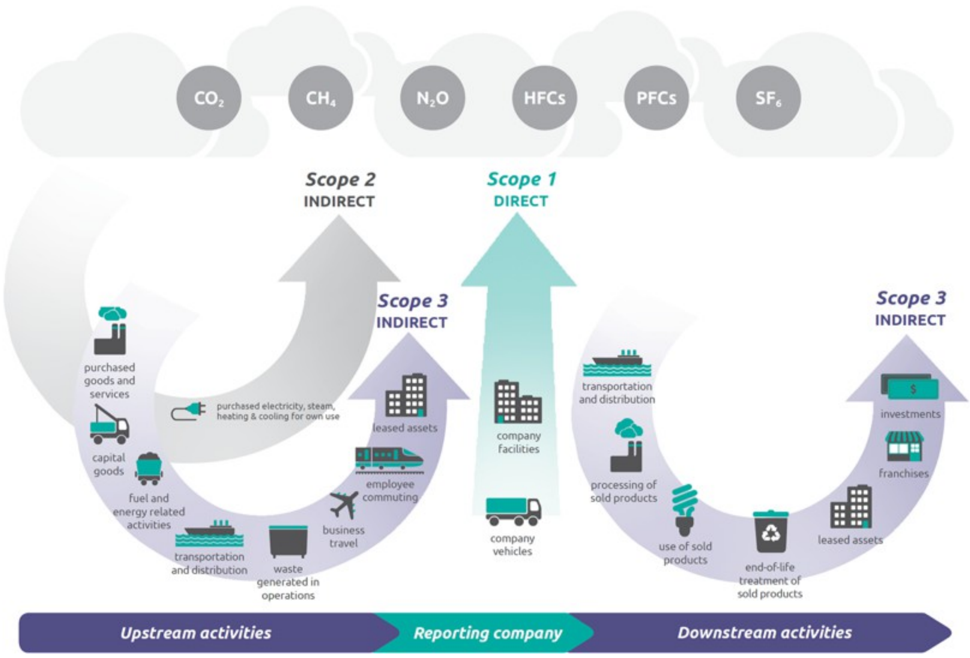

Figure 2-3: GHG Emission Scopes and Sources as per GHG Protocol

An overview of the GHG Assessment Process is as illustrated in Figure 2-4.

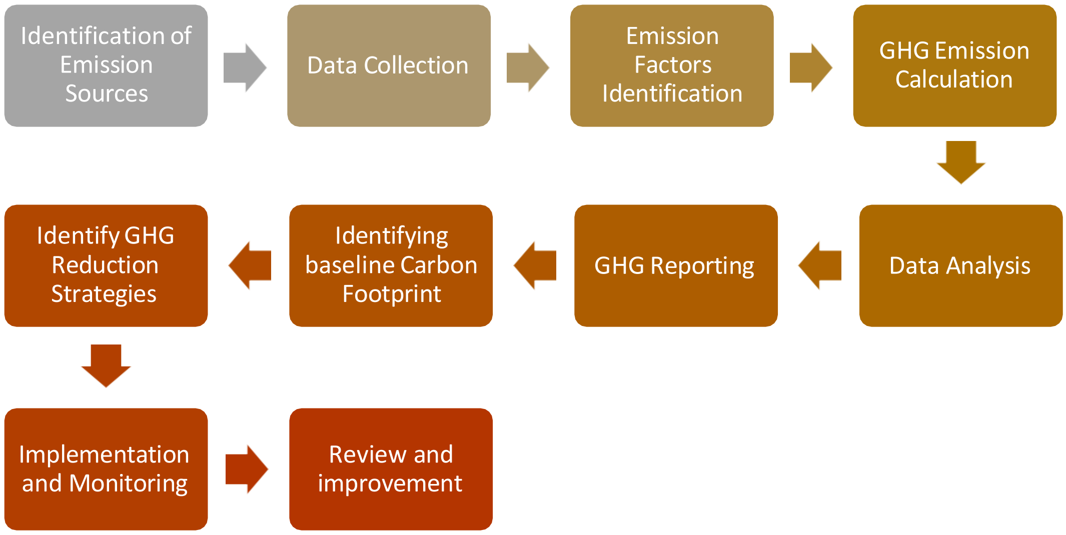

Figure 2-4: Overview of GHG Assessment Process [22]

Table 2-2: Emissions scopes and related sources for a hotel

Emission Scopes	Description	Emission Sources
Scope 1	Direct Emissions from on-site sources	Generators, Boilers, Refrigerant Gas refilling, Fire Extinguisher refilling, Mobile Combustion, Onsite Fuel combustion (LPG, Grass Cutter machines) etc.
Scope 2	Indirect Emissions from imported energy	Purchased Electricity from National Grid
Scope 3	Indirect Emissions from the Supply Chain	Electricity Transmission & Distribution Losses, Water Consumption from National Water Supply, Waste Disposal related emissions only

2.4. Carbon Emission in Hotel Operation

Carbon emissions of hotels primarily revolve around the energy consumption for electricity and HVAC systems. Apart from those, refrigerant refills, waste generation and water usage contribute to the footprint in a major way. Since a major component of over 60% of the footprint is from electricity, it is reflected that electricity consumption is the highest contributor to the hotel's carbon footprint. In the pathway to Net Zero, the first step is to identify the current carbon emission of the hotel, and it is calculated following internationally recognised standards such as ISO14064- 1 and frameworks such as GRI.

Activity data such as utility bills (Consumption values), vehicle fuel records, purchase records, etc. are used as source documents related to each relevant activity that emits GHG—emissions during the process. Utilising appropriate emission factors, the emissions are calculated for each activity for a defined period. Proper data management system that tracks the consumption of energy, water and waste and other resources will enhance the accuracy of Carbon Calculations which properly guide emission reductions and financial savings.

2.5. Sustainable Building Retrofitting

2.5.1. Introduction to Sustainable Building retrofitting

Retrofitting is generally defined as modifying or converting existing facilities, structures or processes without replacing them completely. This modification or alteration may involve additions, removals, rearrangements or replacements of certain parts of the facility, structure or process thereby altering the kind, cost, quantity and quality of the product or service. Even if the structures are built with a lifespan of 5-6 decades, without intermediate alterations, they cannot maintain the sustainable nature of the building. Thereby the necessity of accelerated changes such as green retrofits was highlighted to keep the building operation sustainable. The USGBC, the United States Green Building Council, echoes this urgency, defining green retrofits as upgrades that aim at improving energy and environmental performance, water efficiency and overall occupant comfort while also ensuring financial benefits for the owner. While there are many ongoing debates on the most feasible option comparing demolition vs retrofitting, the vast majority of the environmental, social and economic benefits are well highlighted. Considering the minimized construction waste, resource conservation, minimised pressure on landfills, etc. Retrofitting can be introduced as a compelling strategy that enhances the sustainability of existing structures. As another study suggests, retrofitting can be in different levels ranging from a building component level to entire structures. [23]

Sustainable building retrofitting involves upgrading existing buildings to improve their energy efficiency, reduce their environmental impact, and enhance their overall sustainability. This process includes implementing energy-saving technologies, improving insulation, installing renewable energy systems, and adopting eco-friendly materials. In the context of the hotel industry, retrofitting is crucial for transforming older buildings into sustainable properties that meet modern environmental standards.

2.5.2. Importance & Challenges of Sustainable Retrofitting

Sustainable retrofitting is vital for several reasons. First, it significantly reduces energy consumption and operational costs by enhancing energy efficiency. Second, it helps hotels reduce their carbon footprint and comply with environmental regulations, contributing to global climate change mitigation efforts. Third, sustainable retrofitting improves indoor environmental quality, providing healthier and more comfortable spaces for guests and staff. Lastly, it enhances the hotel's brand reputation, attracting environmentally conscious travelers and investors.

Despite its benefits, sustainable retrofitting presents several challenges. Financial constraints are a major hurdle, as the initial investment for retrofitting can be substantial. Additionally, there may be technical difficulties in integrating new technologies with existing structures. Regulatory barriers and the need for specialized knowledge can further complicate retrofitting projects. Furthermore, disruptions to hotel operations during retrofitting work can affect guest satisfaction and revenue. Addressing these challenges requires careful planning, adequate funding, and collaboration with experts in sustainable building practices.

2.6. Energy Efficient Retrofits

Energy retrofits are a critical area of focus for improving hotel energy performance since energy use in a hotel is a significant contributor to GHG emissions. Improving energy efficiency can significantly reduce the carbon footprint of buildings, making it a crucial strategy for mitigating climate change and promoting sustainable development [24]. Several studies have highlighted the great potential of existing buildings, especially hotel buildings for reducing energy consumption and increasing international attention for energy performance optimization. As Hashempour [25] highlights, multi-criteria problems are increasingly being used in this field, with a focus on environmental and economic factors while a majority of the studies have been focused on environmental objectives like energy consumption and energy demand, followed by economic objectives like LCC, and social objectives like thermal comfort. Also, insulating windows and heating systems have been observed as the most common retrofit measures. This study highlighted the need for using different optimization techniques and the need for developing decision-making tools for improving energy efficiency and conducting a comprehensive and comparative study on energy-efficient measures in different climate conditions in the world.

Another study [26] which aims to critically review existing knowledge on improving energy efficiency in commercial and institutional buildings and to develop a strategy map to achieve improved building energy performance. The study further revealed that the existing buildings require strategies beyond technical advancements to reduce energy demand without compromising occupant health and comfort. Also, it highlights the need for asset management frameworks and the need for further research with more focus on behavioural-based approaches to improve building energy performance.

Another study [27] has researched the decision support methodologies on energy efficiency and energy management in buildings with the aim of analysing the decision support processes related to energy efficiency and enhancement of environmental quality in buildings, categorizing decision criteria, and evaluating decision methodologies. Furthermore, it highlights that even if there are decision support processes considering environmental, energy, financial, and social aspects to optimise the design or operational choices. Also, it highlighted the importance of having a proper decision- making system to consider the continuous development of technological expertise in energy-efficient solutions.

Different studies demonstrated a variety of ways to make existing buildings more energy efficient. A range of upgrades depending on factors like building's age, condition and usage that can be used to purpose and the upgrades can be customized to suit the specific characteristics and energy goals of those buildings [28]. Some common energy efficient upgrades highlighted in the studies were, the improvement of lighting systems, optimization of HVAC system, building envelop upgrades, installation of renewable energy, energy management systems, water heating system improvement, demand response initiatives and building automation and controls. [29]

Several studies have focused on the energy performance of hotels and potential retrofit strategies to be implemented at hotels. Accordingly, Periyannana [30] stated in a study that focused on assessing the costs and benefits of green retrofit technologies through a case study in hotel buildings in Sri Lanka, green retrofits have a positive financial feasibility with less than five years payback period. Among the retrofits, it has been highlighted that solar PV systems, VFDs, LED Lighting, and Key cards have a higher impact on energy performance.

USAID – IPOP Project also highlights the potential of different energy efficiency improvement strategies on the performance of the hotel. Different strategies such as solar PV systems, upgrading to LED bulbs and Temperature settings of Air Conditioners are highlighted in the study [13]. Another major study carried out in Sri Lanka, the Switch Asia Program that assessed Sri Lankan hotel performance, reveals the possibility of improving energy performance in hotels by 17% and emission saving potential of 26% [31]. Another Sri Lankan study that focuses on sustainable consumption practices in Sri Lankan hotels reveals the potential for cost reduction with increased profits with also lower carbon footprints [32].

2.6.1. Lighting upgrades and other energy efficient appliances

Lighting upgrades are a common energy efficiency measure that involves replacing inefficient lighting fixtures with energy-efficient LED bulbs, installing occupancy sensors or daylight sensors to automatically control lighting, and optimizing lighting design to minimize energy use. These upgrades can result in significant energy savings, as lighting typically accounts for a substantial portion of a hotel's electricity consumption [33]. By upgrading the existing lighting system with LED technology the energy will save nearly 75% compared to traditional incandescent bulbs. Since lighting itself accounts for roughly 15% of total building energy consumption, the savings from that lighting upgrade will be a significant portion. Occupancy sensors are another strategy that leads to energy saving. Occupancy sensors and timers for lighting as well as for HVAC will lead to 20-30% energy savings. Automation will adjust usage based on the occupancy and time of the day. As highlighted in Energy Star research, leaving lights in unoccupied spaces may account up to 30% of building's total energy consumption. Choosing energy efficient appliances and equipment has also been identified as a major strategy for reducing energy consumption. Upgrading energy efficient appliances and equipment with higher energy ratings will lead to up to 30% energy savings compared to the standard model. Office equipment itself accounts for nearly 15% of total energy use in commercial buildings. As few studies highlighted, upgrading water heating systems to more energy-efficient models, such as heat pump water heaters or solar thermal systems, is also an effective method for reducing energy consumption for hot water production, especially in buildings with high hot water demand. [29]

2.6.2. HVAC Optimization Strategies

HVAC system optimization and upgrades have been identified as a significant way of improving the energy efficiency of existing buildings in many studies. HVAC upgrades may involve upgrading to more energy-efficient models of HVAC equipment, optimizing HVAC controls for efficient operation, sealing ductwork to prevent air leaks and reduce energy waste, and installing programmable thermostats to optimize temperature control. These upgrades can greatly improve energy savings and provide better comfort for the occupants of the buildings [34]. Among the studies, Chenari clearly depicted that the ventilation systems are responsible for a significant portion of energy consumption in buildings. Also, it highlighted that the developed energy-efficient ventilation methods try to mitigate energy consumption in buildings. Furthermore, it revealed that occupants' behavior regarding ventilation can affect the energy demand in buildings in a significant way. Therefore, it suggests the best way of saving energy while maintaining appropriate indoor air quality through integrating hybrid ventilation strategies. HVAC systems generally account for over 40% of energy use, especially in commercial buildings. Optimization techniques mentioned above can result in 10-30% energy savings.

2.6.3. Passive design strategies and building envelope improvements

Building envelope improvements are another major aspect in energy efficiency upgrades of existing buildings and it involves upgrading insulation, sealing air leaks in windows and doors, and improving windows and glazing to minimize heat gain or loss. These upgrades lead to reduce the energy needed for heating and cooling resulting in improved thermal comfort for building occupants. As El-Darwish highlights in their study on “Retrofitting strategy for building envelopes to achieve energy efficiency”, simple strategies such as solar shading, window glazing, air tightness, and insulation will lead to energy consumption reduction of an average of 33%. [35] 25-30% of Heat loss can be experienced through the building envelop and by improving the insulations, using energy efficient equipment, using energy efficient windows and sealing air leaks in windows will improve the building performance. Further, integrating passive concepts such as orientation of the building, using shading devices will result in 20-40% of heating & cooling energy needs. As highlighted by International Energy Agency, Overall, it will be around 30-50% energy saving compared to the conventional buildings. As a design strategy daylight integration can be used though skylights, light shelves, windows etc. and it will lead to 25-80% reduction of energy consumption. As another study conducted by US Department of Energy reveals, natural ventilation strategies can result in reduction of cooling related energy by up to 50%. [36]

2.6.4. Incorporating renewable energy systems

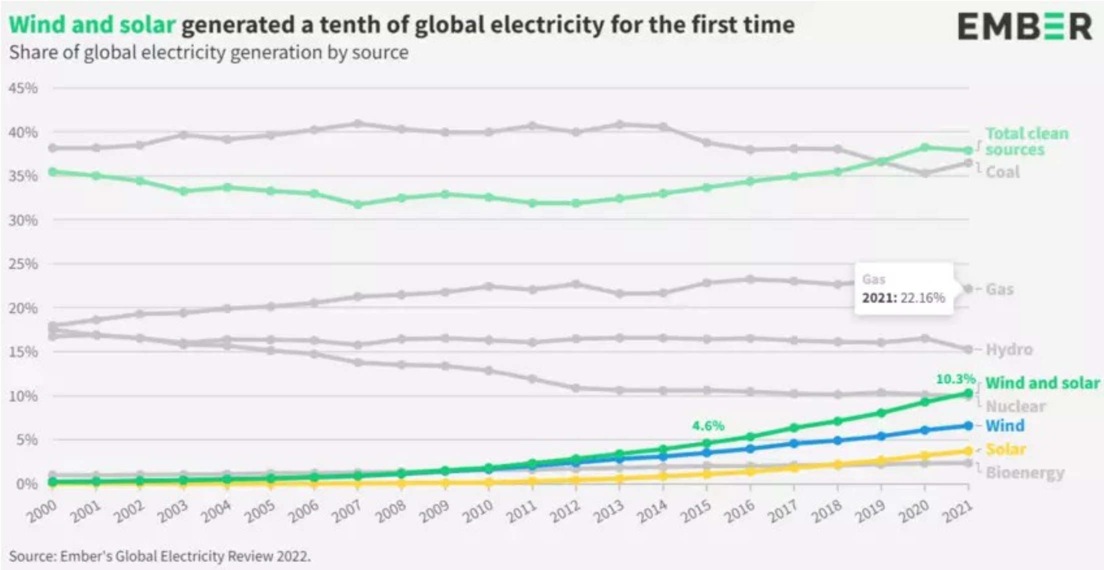

Figure 2-5: Share of global electricity generation by source: Wind and Solar generated a 10% of global electricity for the first time

As demonstrated above, another strategy is installation of renewable energy systems. These may be installation of solar panels or wind turbines. Apart from those two increasingly implementing strategies, there are other renewable energy sources like geothermal energy and bioenergy. These interventions will greatly support in reduction of fossil fuel combustion and ultimately reducing the greenhouse gas emissions associated with energy generation, making them an effective strategy for enhancing sustainability. Most importantly, it is the major technical solution related to the trending concept of Net Zero Energy/ Carbon Buildings. [37] Likewise, renewal energy systems such as Solar photovoltaic panels (PV) have the potential of offsetting significant component of building energy consumption. (U.S. Department of Energy) With the decreasing initial cost of installation, the Solar Photovoltaics will be much common in the future and this has the potential of reducing the greenhouse gas emission by 23.6 million tons annually by 2030. As the graph in Figure 2-5 clearly illustrates, wind and solar power generated over 10% of the world's electricity, marking a significant milestone in 2021. This achievement was reached by 50 countries.

As World Green Building Council highlights in their Advancing Net Zero Status Report 2022, Energy efficiency measures that are presently available have the potential to reduce global emissions by 48% by 2030, with 43% of the overall reductions emanating from buildings. Additionally, these measures can aid grid decarbonization lowering costs, and enhancing resilience, durability, comfort, and productivity. [38]

2.6.5. Energy Management Systems

Energy management systems also allow for real-time monitoring and optimization of energy use, making them increasingly dominant in existing buildings. These systems enable improved control and management of building energy consumption, and it leads to more efficient energy use and reduced waste by adjusting lighting and HVAC settings based on occupancy, scheduling, and weather conditions. [39] As another study reveals, implementing a proper energy monitoring system with regular benchmarks will enable energy saving through the behavioral changes up to 20%. Meanwhile, buildings with proper energy management systems that regularly track and analyze can lead to 15% energy savings. Properly designated building should be commissioned before a handing over to the client. Likewise, those type of properly commissioned buildings will lead to reduction of 5-20% of useful energy. It will save 8-20% of energy costs and indoor air quality will be improved by 10-50% as highlighted in Building Commissioning Association.

Another energy efficiency related intervention is demanding response programs which offer financial incentives for buildings to participate in energy demand reduction during peak demand periods and contribute to grid stability reducing the need for additional power generation, resulting in environmental and financial benefits. Building automation and control systems are also increasingly popular for optimizing the operation of various building systems, such as lighting, HVAC, and other energy-consuming equipment, minimizing energy waste, and ensuring that building systems operate at their optimal levels. These systems use advanced sensors, controls, and algorithms to optimize energy use based on building occupancy, weather conditions, and other factors.

In conclusion, energy efficiency upgrades have become a crucial strategy for enhancing sustainability in existing buildings, since they can significantly decrease energy consumption, greenhouse gas emissions, and the environmental footprint of buildings. The range of energy efficiency upgrades such as lighting upgrades, HVAC upgrades, building envelope improvements, renewable energy installations, energy management systems, water heating upgrades, demand response programs allow for customizing to the specific characteristics and performance goals of each building.

2.7. Water Saving Retrofits

As another main sustainability enhancement intervention is water efficient upgrades in building water systems. As the global population continues to grow and climate change exacerbates existing water scarcity issues thus conserving water has become a tremendous concern. However, implementing these measures in existing buildings is crucial, as buildings are responsible for a significant proportion of water consumption worldwide.

2.7.1. Low flow water fixtures

One of the most effective water conservation measures for hotel buildings is the implementation of low-flow faucets and dual-flush toilets. Low-flow faucets use significantly less water than traditional faucets, while dual-flush toilets allow users to choose between a low-flow and high-flow option depending on their needs. Existing faucets can be improved by adding aerators and it will lead to nearly 80% less water wastage. By reducing water consumption in this way, significant amounts of water can be conserved, particularly in regions that are facing water scarcity or water stress. [40] As highlighted in the United States Environmental Protection Agency’s reports, retrofitting water fixtures replacing low flow toilets, showerheads and other faucets etc. has the potential to reduce the water consumption by up to 30-50%. Few other studies also highlight that upgrading the water fixtures is the most cost-effective way of reducing the water consumption throughout the life cycle.

2.7.2. Rainwater Harvesting

Another important water conservation measure for existing buildings is the installation of rainwater harvesting systems. These systems collect rainwater from rooftops and other surfaces and store it for later use, such as for watering plants or flushing toilets. By using rainwater instead of potable water for these purposes, significant amounts of water can be conserved, particularly in regions where potable water is scarce. [41] Installing rainwater harvesting systems and utilizing the collected rainwater for irrigation and toilet flushing will reduce the demand for treated water and it will lead to 50-90% of outdoor water usage reduction.

2.7.3. Greywater recycling

Several studies highlight the importance of implementing greywater recycling practices in their premises specially the buildings which have higher wastewater generation in general washing activities like laundries, kitchen and showers etc. The wastewater generated from those activities can be easily treated and reused for different purposes such as landscape irrigation, vehicle washing and etc. Through these practices, it has the potential of indoor water use reduction by 30-50% specially in commercial buildings. These will reduce the extraction of freshwater from groundwater sources.

2.7.4. Water Efficient Irrigation

Another sustainable practice of managing water is reducing potable water for irrigation requirements. As Green Building Council of Sri Lanka highlights in their rating system, potable water usage elimination will save cost and will enable building occupants to be more aware of their sustainable water usage practices. Instead of potable water use, collected air conditioner condensate, harvested rainwater, ground water, recycled greywater can be used for irrigation.

As another important intervention highlighted by the Environmental Protection Agency in United States, installing weather based or soil moisture-based irrigation controllers will optimize outdoor irrigation through scheduling watering based on plant needs and weather conditions. These smart irrigation systems can save water by 20-50% of outdoor water needs compared to conventional practices. As another practice and intervention, adopting xeriscaping techniques can be identified where drought tolerant plants will be used minimizing water demand for landscaping features and reducing outdoor water consumption. These techniques will save nearly 50-75% of water compared to conventional and traditional landscaping practices.

2.7.5. Other water related interventions

Apart from the above-mentioned tactics, installing water meters and/or submeters is really important in minimizing water consumption in a building since they will allow to monitor and track the water usage, identify abnormalities as well as high consumption areas leading towards opportunity reduce water consumption. As highlighted in the Building Owners and Managers Association International, submetering for individual units will lead to 20-30% reduction in water consumption.

In conclusion, water conservation measures are an important intervention for hotel buildings, particularly in regions facing water scarcity or water stress. Measures such as low-flow faucets, dual-flush toilets, and rainwater harvesting systems can significantly reduce water consumption and promote sustainable water use practices, leading to cost savings and demonstrating a commitment to environmental responsibility. As such, building owners should consider implementing these measures as part of their overall sustainability strategy.

2.8. Resource Consumption Reducing Retrofits

Sustainable resource consumption is a critical aspect of sustainability in hotel buildings. Recycling and waste sorting programs, composting programs, salvaging and repurposing materials, upcycling and repurposing projects, and waste reduction in operations are effective strategies that can minimize the environmental impact of buildings and promote a circular economy approach. These strategies can significantly reduce waste generation, promote resource conservation, and foster sustainable consumption practices in existing buildings. In this aspect both building occupants and facility managers can play a crucial role in implementing and promoting these measures through awareness campaigns, education, and behavior change initiatives.

As a common practice identified in this scenario is the proper solid waste management practices. Under this, waste segregation can be considered as a common initiative and moving further, the 3R concept as well as the circular economy principles can be integrated in building facility management to reduce resource consumption and waste generation. Also, it has been identified as an important initiative to maximize the recycling and reusing of waste avoiding sending to waste dump yards. Meanwhile few studies have highlighted the importance of managing the hazardous waste carefully reducing the hazard to the occupants and the environment through proper disposal methods.

Implementing waste reduction measures in building operations can significantly reduce waste generation and promote sustainable consumption practices. For example, reducing paper usage through digitalization of documents, promoting reusable items, and minimizing single-use items, such as plastic cups or utensils, can contribute to waste reduction efforts. These waste reduction measures not only reduce the environmental impact of building operations but also foster a culture of sustainability among building.

2.8.1. Paperless practices

Paperless practices including transitioning to digital documents avoiding printing whenever necessary will save paper up to 50-75% of paper consumption. As few studies reveal, average office worker in bank uses about 10,000 sheets per year. As GreenBiz facts highlight, each worker consumes around 10,000 A4 sheets each year accounting nearly 70% of the office waste as paper waste. Also, paper recycling will save almost 13 trees, 4100 kW of electricity and over 30,000 liters of water. As Green Education foundation highlights in their report, approximately 30% of printed paper is discarded without ever being used.

Avoiding printing specially through promoting the practice of electronic billing and invoices as well as when printing always trying to print double sided will reduce paper usage up to 50%. As Minnesota Pollution Control Agency highlights in their report, Double sided printing can save an average office 240 reams of paper per year. Apart from that, the default settings of printers can be changed by setting as draft mode, reduced margins, multiple pages per sheet etc. to reduce paper consumption for printing. Also, unnecessary printings can be avoided to the maximum possible. These practices will lead to over 50% of paper and ink/toner savings. Implementing print management software and practices such as monitoring print jobs, setting quotas etc. will reduce printing volume up to 20%.

Digitalizing all possible activities will also help reduce paper consumption by over 80%. Digital storage will also save substantial amount of paper as well as space. For an instance, an office space, 13 sq ft of space per employee will be saved by this digital transformation leading to nearly 25% of paper saving.

2.8.2. Green Procurement Policy

Having a green purchasing & procurement policy for both durable and non-durable goods is important since it looks at the life cycle perspective of goods and avoid purchasing unsustainable products with lower lifetime. Always, the purchasing decisions can be made considering the eco friendliness of the materials specially which are made of recycled products and/or with eco-friendly certifications and materials that support circular economy principles. These sustainable procurement practices will lead to a carbon footprint reduction of nearly 30%.

In conclusion, Sustainable resource consumption strategies are critical for enhancing sustainability in existing buildings. Recycling and waste sorting programs, composting programs, salvaging and repurposing materials, upcycling and repurposing projects, and waste reduction in operations are potential strategies that can be implemented to minimize the environmental impact of buildings and promote a circular economy approach. These strategies can significantly reduce waste generation, promote resource conservation, and foster sustainable consumption practices in existing buildings.

2.9. Other Sustainable Retrofits

Existing buildings can adopt various sustainability initiatives rather than the energy efficiency upgrades, water efficiency upgrades, IEQ enhancement strategies and sustainable resource consumption strategies. Some of those strategies are enhancement of biodiversity, education and awareness programs, green management practices, green transportation practices and etc. Greenery involvement is all-time sustainability enhancement intervention. Some of the strategies are green walls, green facades, green roofs, sky courts and etc. All those strategies involve in different ways to enhance the performance of the buildings. They can mitigate the urban heat island effect, improve stormwater management by reducing runoff, provide insulation to reduce energy consumption for heating and cooling, and promote biodiversity by creating habitats for plants and animals. This biodiversity enhancements within and around buildings can also contribute to improve air quality, provide recreational spaces for building occupants enhancing the wellbeing and productivity of employees. [42]

Green management and procurement policies can promote responsible sourcing, reduce environmental impacts, and support sustainable markets. Such policies prioritize the use of sustainable materials, products, and services in hotel building operations, maintenance, and renovation projects. Especially Green management practices are really important since each decision is taken through the management decisions. Having a sustainability related division or a team is extremely important since all the maintenance related tasks can be managed as per the required standards. Consumption records can be monitored through their involvement and identify the potential improvements throughout the lifecycle of the building. Having environment and sustainability related policies and implementing them is extremely important to maintain and enhance sustainability of hotel buildings. [28]

In conclusion, hotel buildings can adopt various sustainability enhancement interventions beyond energy efficiency upgrades, water efficiency upgrades, and sustainable resource consumption strategies. These interventions include greenery involvement, biodiversity enhancements, education and awareness programs, green management and procurement policies, and performance monitoring and reporting systems. Adopting these interventions can promote responsible resource management and contribute to the sustainability performance of hotel buildings.

2.10. Different multi criteria decision support frameworks

With a wide variety of sustainability enhancement strategies available and with different multi criteria tools available for guiding towards decision making regarding improvement of building sustainability performance, it's crucial to identify the most suitable method for this study which will be a simplified, convenient framework that will give accurate results helping better decision making. Further study will be carried out to identify the available multi criteria decision support frameworks and models. This study will further focus on existing and most upgraded sustainability assessment guidelines published by the local and international parties related to the Sustainable Built Environment. A proper evaluation will be carried out comparing the existing multi criteria decision making models and identify gaps.

Among the available multi-criteria decision support frameworks for sustainability enhancement in buildings, three frameworks have gained significant recognition in the literature. Those are Analytical Hierarchy Process (AHP), Analytic Network Process (ANP) and Multi Attribute Utility Theory (MAUT).

As highlighted in several studies, The Analytical Hierarchy Process (AHP) is widely employed in sustainable building practices because of its hierarchical structure and the ability to compare alternatives in pairs. AHP or Analytical Hierarchy Process allows decision-makers to systematically assess and prioritize sustainability factors by deconstructing complex decisions into a series of comparisons. This structured approach enables informed decision-making by evaluating the relative significance of criteria and alternatives. The straightforward and adaptable nature of AHP has made it a preferred methodology in numerous studies focused on sustainability assessments. [43]

Another Decision-making framework is the Analytic Network Process (ANP) that builds on the foundation of the AHP by establishing interdependencies and feedback among criteria and alternatives. The ANP recognizes that sustainability decision-making involves complex relationships and interactions among various factors. By analyzing network structure and dependencies, ANP or Analytic Network Process provides a broader evaluation framework. It allows decision makers to capture the complex relationships between criteria, while assessing the impacts of decisions on the overall sustainability process. Analytic Network Process has been successfully used in sustainable building studies to address the complexities of decision-making processes.[44]

The other most prominent decision support framework that is widely used is Multi-Attribute Utility Theory (MAUT) and it takes a different approach by combining the preferences of decision makers through utility functions. Multi-Attribute Utility Theory evaluates alternatives based on multiple attributes and their relative importance, allowing decision makers to express their subjective preferences. This framework accommodates the different perspectives and priorities of stakeholders involved in sustainability decision making. By aggregating attribute utilities, Multi-Attribute Utility Theory enables a comprehensive assessment of sustainability improvement strategies in buildings. Its ability to incorporate subjective judgments makes it a valuable tool for decision makers seeking to balance different objectives and preferences. [45]

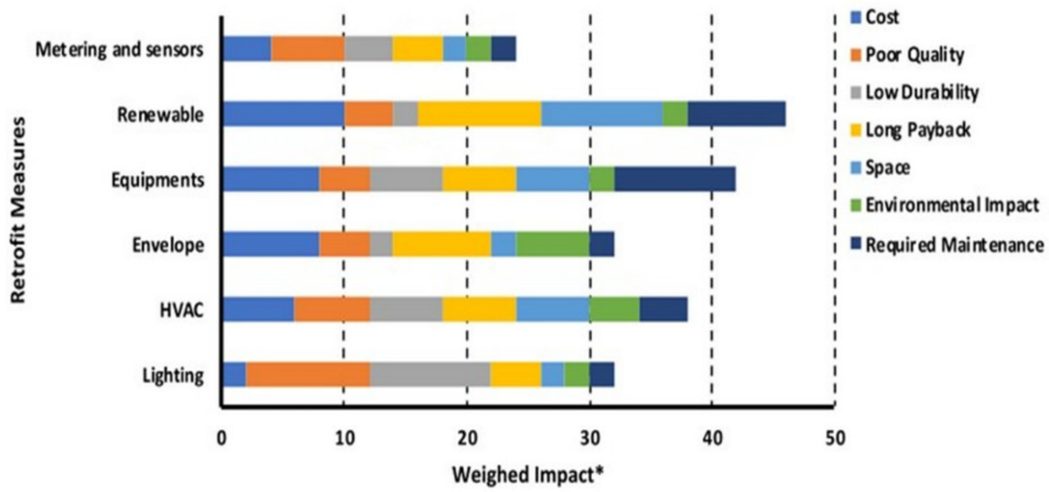

Figure 2-6: Factors of concern in retrofitting decisions [64]

It is important to note that above mentioned frameworks are just a few examples of the diverse range of multi-criteria decision support methodologies available for sustainability assessments in buildings. Each framework has its unique features, strengths, and applications, allowing decision-makers to select the most suitable approach based on the specific context and requirements of the assessment. Further research and comparative studies can contribute to a deeper understanding of these frameworks' capabilities and guide their appropriate usage in sustainable building decision-making processes.

The Analytical Hierarchy Process (AHP) was selected for this study since it is a robust framework for systematic decision-making for the complex and multi-dimensional nature of the case. Since AHP enables the structured breakdown of the retrofitting problems into a hierarchy of more manageable sub-problems, allowing comprehensive evaluation of both qualitative and quantitative criteria such as Initial Cost, Emissions Reduction, Maintenance Requirement, and Adaptability. Also, by facilitating pairwise comparisons and incorporating expert judgements, AHP ensures that the decisions are based on a balanced and informed analysis. It is also flexible for customising to address unique climatic conditions, operational challenges, and budget constraints faced by Sri Lankan Hotels. Furthermore, AHP’s capacity to prioritise retrofit options based on their potential impact and feasibility ensures effective resource allocation, aligning retrofit decisions with both sustainability goals and financial objectives. It makes AHP a valuable tool to develop a strategic framework for sustainable retrofitting, ultimately aiding the transition towards net zero hotels in Sri Lanka.

2.11. Research Gap

Despite the growing focus on sustainability in the hotel sector, there remains a significant gap in the availability of comprehensive frameworks that guide the assessment and implementation of sustainable retrofitting strategies specifically tailored for hotels. Current literature and industry practices often provide fragmented approaches lacking an integrated systematic framework that considers the unique operational, financial and environmental challenges of the hotel sector. While there are existing frameworks such as LEED Certification, BREEAM and WELL Building Standard, these are generally broad and not specifically tailored to the needs of hotel operations. This research aims to fill this gap by developing a robust framework that incorporates baseline performance evaluation, potential retrofit identification, retrofit prioritization and implementation guidance. By addressing this gap, the study contributes to the creation of practical, scalable solutions that can drive hotel industry towards greater sustainability and towards decarbonized future.

CHAPTER 3

3. Methodology

This chapter focuses on the research methodology employed to identify sustainable retrofitting strategies for tourist hotels and resorts. The primary objective of this research is to develop actionable guidelines to enhance the sustainability of the hotels, maintaining their operational efficiency and guest satisfaction. A comprehensive approach has been taken to achieve this integrating both qualitative and quantitative research techniques as illustrated in Figure 3-1. This chapter provides a detailed description of the research design, data collection methods and analysis procedure in each step.

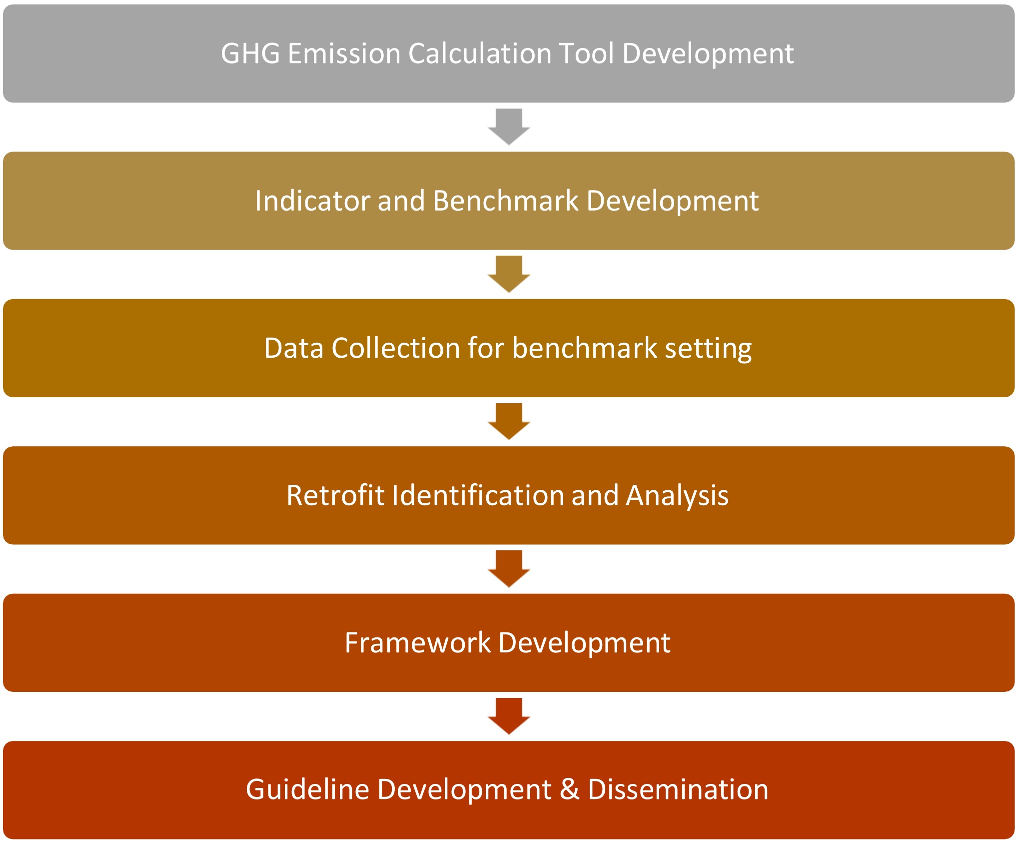

Figure 3-1: Research Methodology Summary

3.1. GHG Emission Calculation Tool Development

As the first step of the process, the Organizational GHG Emission calculation tool was developed based on the standards of ISO14064-1 and the Greenhouse Gas Protocol. All the emission sources related to a hotel were identified based on expert reviews and available hotel GHG Reports. Figure 3-2 illustrates the breakdown of the identified emission sources.

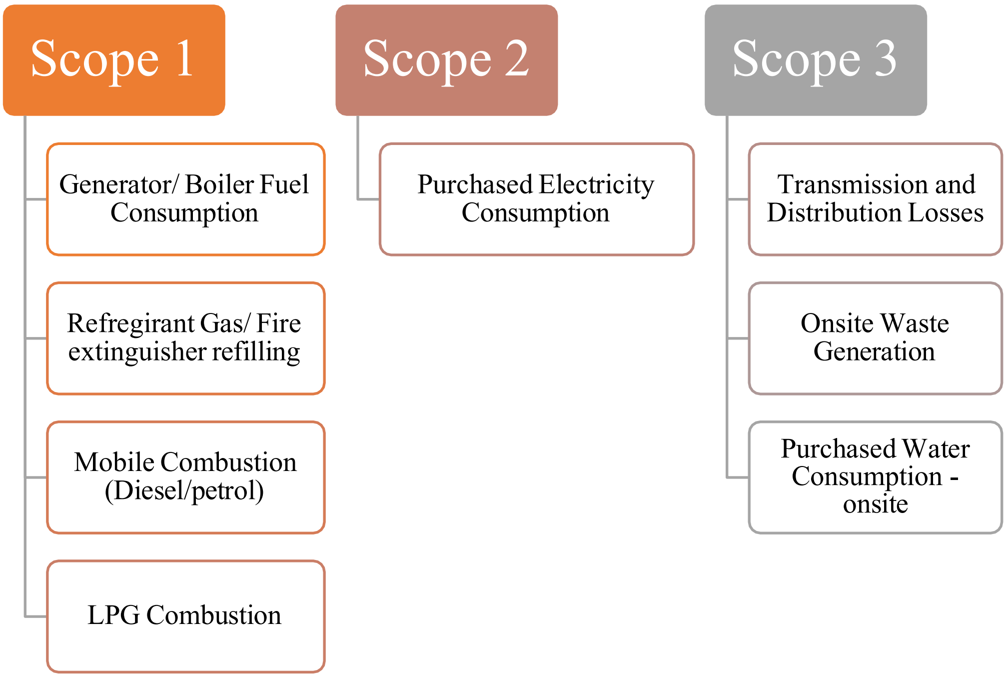

Figure 3-2: GHG Emission Sources Selected for the Study

According to the standard, GHG Protocol and GHG Accounting principles, all Scope 1 and 2 emissions are mandatory to be accounted and there is flexibility to select the Scope 3 emission categories out of the available 15 categories. Since this is mostly to identify the impact of building retrofitting, transportation-related Scope 3 emissions were excluded from the calculation. The GHG Emission calculator was developed based on an excel sheet for the ease of use by the stakeholders.

Following the standards, the emission sources were selected for the study and included in the GHG Emission Calculation Tool. Table 3-1 describes the emission sources and required data for the calculation tool.

Table 3-1: Selected emission sources for the study				
Scope	**Emission Source**	**Data Required**	**Symbol**	**Unit**
Scope 1	Generator	Annual fuel consumption	AD_{1G}	Liters
	Boiler	Annual fuel consumption	AD_{1B}	Liters/kgs
	LPG	Annual consumption	AD_{1LP}	Tonnes
	Petrol/Diesel	Annual fuel consumption for vehicles or any other	AD_{1V}	Liters
	AC gas refilling R22, R32, R410a, R134a etc.	Annual refilling quantity	AD_{1Ref}	kg
	Fire Extinguisher refilling	Annual refilling quantity	AD_{1F}	kg
Scope 2	Purchased electricity	Annual electricity consumption from grid	AD_{2-Elec}	kWh
Scope 3	Transmission and Distribution loss	N/A	$AD_{3-T\&D}$	kWh
	Waste Disposal	Annual waste generation details separately for different waste types	AD_{WD}	Tonnes
	Water Consumption	Annual water consumption from NWSDB line	AD_{WC}	m^3

Equation 3-1 is the basic formula, used for all the calculations embedded in the tool.

$$\text{GHG Emission} = \text{Activity Data} \times \text{Emission Factor} \quad (3\text{-}1)$$

Selection of Emission Factors

The emission factor selection has been prioritized according to National, Regional and International categories. The emission factor for electricity was obtained from the latest Sri Lanka Energy Balance Report – 2021[46] published by the Sri Lanka Sustainable Energy Authority. Transmission and Distribution loss percentage was discovered from CEB Statistical Digest 2021 [47]. Most of the Emission factors were selected from DEFRA – Department for Environment, Food and Rural Affairs 2023 database since local emission factors were not available.

For an example if the GHG emission is required for the source of electricity consumption of the hotel; the activity data is the annual energy consumption in kWh (e.g.: 3,520,961 kwh) and the Emission Factor is 0.4278 $kgCO_{2e}$/kWh.

$$Annual\ GHG\ Emission\ from\ Electricity\ Consumption$$
$$= 3{,}520{,}961 \times 0.4278 = 1{,}506{,}267\ kgCO2e\ (1{,}506.27\ tCO2e)$$

Formulas to be Embedded in the Calculator

Referring to the symbols in Table 3-1, Equation 3-1 was further developed for each emission source identified as per Equation 3-2 to 3-12. All these equations were developed adhering to the requirements of carbon accounting standards in ISO 14064-1 and GHG Protocol. Emission factors selected for each source are given in Table 3-2.

Scope 1: Direct GHG Emissions – Onsite

$$EM_{1G} = AD_{1G} \times EF_{1G} \tag{3-2}$$

EM_{1G}	=	Annual GHG Emission due to Generator fuel consumption ($kgCO_2e$)
AD_{1G}	=	Annual fuel consumption (Liters)
EF_{1G}	=	Relevant fuel emission factor ($kgCO_2e$ /Liter)

$$EM_{1B} = AD_{1B} \times EF_{1B} \tag{3-3}$$

EM_{1B}	=	Annual GHG Emission due to Boiler fuel consumption ($kgCO_2e$)
AD_{1B}	=	Annual fuel consumption (Liters or kg)
EF_{1B}	=	Relevant fuel emission factor ($kgCO_2e$ /Liter or $kgCO_2e$/kg)

$$EM_{1LP} = AD_{1LP} \times EF_{LP} \quad (3\text{-}4)$$

EM_{1LP}	=	Annual GHG Emission due to LPG consumption ($kgCO_2e$)
AD_{1Lp}	=	Annual LPG consumption (Tonne)
EF_{1LP}	=	LPG consumption related emission factor ($kgCO_2e$/Tonne)

$$EM_{1V} = AD_{1V} \times EF_{1V} \quad (3\text{-}5)$$

EM_{1V}	=	Annual GHG Emission due to Vehicle fuel consumption ($kgCO_2e$)
AD_{1V}	=	Annual fuel consumption (Liters)
EF_{1V}	=	Relevant fuel emission factor ($kgCO_2e$ /Liter)

$$EM_{1Ref} = AD_{1Ref} \times EF_{1Ref} \quad (3\text{-}6)$$

EM_{1Ref}	=	Annual GHG Emission due to refrigerant gas refills ($kgCO_2e$)
AD_{1Ref}	=	Annual Refrigerant gas refill quantity (kg)
EF_{1Ref}	=	Relevant fuel emission factor ($kgCO_2e$ / kg)

$$EM_{1F} = AD_{1F} \times EF_{1F} \quad (3\text{-}7)$$

EM_{1F}	=	Annual GHG Emission due to Fire extinguisher refills ($kgCO_2e$)
AD_{1F}	=	Annual Fire extinguisher refill quantity (kg)
EF_{1F}	=	Relevant fuel emission factor ($kgCO_2e$ / kg)

`

Scope 2: Indirect GHG Emissions – Purchased Electricity

$$EM_{2-Elec} = AD_{2-Elec} \times EF_{2-Elec} \quad (3\text{-}8)$$

EM_{2-Elec}	=	Annual GHG Emission due to purchased electricity consumption ($kgCO_2e$)

AD_{2-Elec}	=	Annual electricity consumption (kWh)
EF_{2-Elec}	=	Grid Electricity emission factor – Sri Lanka ($kgCO_2e$ /kWh)

Scope 3: Indirect GHG Emissions – Other

$$EM_{3-T\&D} = AD_{3-T\&D} \times EF_{3-T\&D} \quad (3\text{-}9)$$

$EM_{3-T\&D}$	=	Annual GHG Emission due to Transmission and Distribution Loss ($kgCO_2e$)
$AD_{3-T\&D}$	=	Annual T&D Loss (kWh)
$EF_{3-T\&D}$	=	Grid Electricity emission factor – Sri Lanka ($kgCO_2e$ /kWh)

$$AD_{3-T\&D} = AD_{2-Elec} \times \frac{TD_{Grid}}{(1 - TD_{Grid})} \quad (3\text{-}10)$$

TD_{Grid}	=	Transmission and Distribution Loss (%)

$$EM_{WD} = AD_{WD} \times EF_{WD} \quad (3\text{-}11)$$

EM_{3-WD}	=	Annual GHG Emission due to on-site waste generation and disposal ($kgCO_2e$)
AD_{3-WD}	=	Annual waste generation quantity (Tonne)
EF_{3-WD}	=	Relevant fuel emission factor ($kgCO_2e$ /Tonne)

$$EM_{WC} = AD_{WC} \times EF_{WC} \quad (3\text{-}12)$$

EM_{WC}	=	Annual GHG Emission due to Potable water consumption ($kgCO_2e$)
AD_{WC}	=	Annual potable water consumption (m^3)
EF_{WC}	=	Water Consumption emission factor ($kgCO_2e$ / m^3)

Table 3-2: Emission Factors and sources used

Source ID	**Emission Source**	**Emission Factor**	**Unit**	**Emission Factor Source**
1	Annual Diesel consumption (Generators)	2.6594	kg CO_{2e} /Liter	DEFRA 2023
2	Annual Diesel consumption (Mobile)	2.6594	kg CO_{2e} /Liter	DEFRA 2023
3	Annual LPG Consumption	2939.3609	kg CO_{2e} /Ton	DEFRA 2023
4	Annual Petrol Consumption	2.3450	kg CO_{2e} /Liter	DEFRA 2023
5	Annual Fuelwood Consumption (Biomass Boiler if available)	43.8933	kg CO_{2e} /Ton	DEFRA 2023
6	Annual Refrigerant gas refilling - R22	1760.0000	kg CO_{2e} /kg	DEFRA 2023
7	Annual Refrigerant gas refilling - R32	677.0000	kg CO_{2e} /kg	DEFRA 2023
8	Annual Refrigerant gas refilling - R134a	1300.0000	kg CO_{2e} /kg	DEFRA 2023
9	Annual Refrigerant gas refilling - R410	1924.0000	kg CO_{2e} /kg	DEFRA 2023
10	Annual Fire Extinguisher refilling - CO_2	1.0000	kg CO_{2e} /kg	DEFRA 2023
11	Annual Purchased Electricity Consumption - Hotel	0.4278	kg CO_{2e} /kWh	SLSEA EB Report 2021
12	Annual Purchased Electricity Consumption - Laundry Service	0.4278	kg CO_{2e} /kWh	SLSEA EB Report 2021
13	Annual T&D Losses	0.4278	kg CO_{2e} /kWh	SLSEA EB Report 2021
14	Annual Biodegradable waste (Reuse)	0	kg CO_{2e} /Ton	DEFRA 2023
15	Annual Paper and Cardboard waste	21.281	kg CO_{2e} /Ton	DEFRA 2023
16	Annual plastic & Polythene waste	21.281	kg CO_{2e} /Ton	DEFRA 2023
17	Annual E waste	21.281	kg CO_{2e} /Ton	DEFRA 2023
18	Annual Waste Oil	21.281	kg CO_{2e} /Ton	DEFRA 2023
19	Annual Mixed waste (other)- Recycle	21.281	kg CO_{2e} /Ton	DEFRA 2023
20	Annual Garden waste- Compost	8.912	kg CO_{2e} /Ton	DEFRA 2023
21	Annual Water Consumption - Hotel	0.150	kg CO_{2e} /m^3	DEFRA 2023
22	Annual Water Consumption - Laundry Service	0.150	kg CO_{2e} /m^3	DEFRA 2023

The selected emission factors were based on the guidance provided in the GHG Protocol. For regional data, the grid electricity emission factor was sourced from the Energy Balance Report (2021) published by the Sri Lanka Sustainable Energy

Authority. For other emissions, the globally recognized DEFRA database (latest version) was used. DEFRA was chosen over other global databases due to its convenience, consistency, and ability to reduce uncertainties associated with using multiple emission factor sources. Additionally, DEFRA's comprehensive and regularly updated dataset aligns with international frameworks, ensuring reliability and relevance to the study while maintaining methodological consistency.

The calculator analyses the data and presents it in scope and source-wise emissions. This is the baseline emission that is considered in this analysis forward. The energy balance of the hotel is also analysed and presented in graphical form. Finally, the results are compared with industry benchmarks and present hotel performance in Energy, Water and Waste areas. Low-performing areas are highlighted, and users are encouraged to analyse the retrofit options in those recommended areas as the next step.

This calculator includes the comparison of the emissions generated within a year with industrial benchmarks for Energy, GHG Emissions, Water usage and Waste Generation. After this comparison, it shows the recommended areas of retrofitting, Energy, Water or Waste.

3.2. Indicator Selection and Benchmark Development

The most outstanding international sustainability benchmarking scheme developed for hotels is the Cornell Hotel Sustainability Benchmarking Index 2023 developed by GreenView with Cornell University. This benchmarking scheme allows Carbon, water and energy related measures into several benchmarks [48]. The mentioned measures/indicators are as follows.

- INDICATOR 1: HCMI Rooms Footprint Per Occupied Room (kgCO_2e)
- INDICATOR 2: Hotel Carbon Footprint Per Room (kgCO_2e)
- INDICATOR 3: Hotel Carbon Footprint Per Occupied Room (kgCO_2e)
- INDICATOR 4: Hotel Carbon Footprint Per Square Meter (kgCO_2e)
- INDICATOR 4a: Hotel Carbon Footprint Per Square Foot (kgCO_2e)
- INDICATOR 5: Hotel Energy Usage Per Occupied Room (kWh)
- INDICATOR 6: Hotel Energy Usage Per Square Meter (kWh)
- INDICATOR 6a: Hotel Energy Usage Per Square Foot (kWh)

- INDICATOR 7: HCMI Meetings Footprint Per SQM-HR ($kgCO_2e$)
- INDICATOR 8: Hotel Water Usage Per Occupied Room (L)
- INDICATOR 9: Hotel Water Usage Per Square Meter (L)
- INDICATOR 9a: Hotel Water Usage Per Square Foot (L)
- INDICATOR 10: HWMI Rooms Footprint Per Occupied Room (L)
- INDICATOR 11: HWMI Meetings Footprint Per SQM-HR (L)
- INDICATOR 12: Hotel Energy from Renewables (%)

These indicators are developed per occupied room and per unit area. When these indicators are measured per occupied room, it normalizes the data accounting for fluctuations in occupancy rates. This approach ensures that hotels can effectively identify inefficiencies, implement targeted sustainability measures and monitor improvements regardless of the occupancy variations. This point was validated by the hotel stakeholders involved in the data collection process of the research. Thus, the following four Key Performance Indicators were selected to measure the emissions, energy, water and waste generation of the hotels.

- GHG Emissions / Occupied Room ($kgCO_2e$)
- Electricity Consumption/ Occupied Room (kWh)
- Water Consumption/ Occupied Room (m^3)
- Waste Generation/ Occupied Room (kg)

3.3. Data Collection for Benchmark Setting

- Selection of Hotel Type

In the context of sustainable practices, the selection of small to medium size hotels and resorts was based on few key factors. This categorization allows for a focused analysis of hotels that typically operate on a scale conducive to implementing sustainable retrofitting strategies without complexities of large operations. The level of commitment to sustainability within the industry was a primary consideration which was assessed through various factors including existing sustainability certifications, participation in green programs and publicly available environmental performance data. Additionally, the geographical locations were also considered ensuring a diverse representation of environmental conditions and regional sustainability practices. Accordingly, 18 hotels were selected for this study with a total of 1941 rooms. This sample size is statistically significant for capturing a comprehensive range of data on sustainable practices and retrofitting strategies. Each hotel's sustainability initiatives were considered and only those who have already begun their journey in sustainability were selected. Thus, the study aims to identify best practices for formulating recommendations to be applied across similar hotel types, finally contributing to a broader goal of achieving sustainability in the hospitality industry.

- Data Collection

Data collection was based on two methods: surveys and interviews.

Survey - An Excel sheet was shared to obtain the annual consumption/ generation data related to the emission sources listed in Table 3-1. This method ensured a systematic collection of quantified data essential for benchmarking. Separate tabs have been added to record annual data related to the building.

Interviews with Technical Professionals – Separate discussions were conducted with technical experts including MEP Engineers, Maintenance Engineers, Facility Managers, and Sustainability Consultants aiming to identify recently implemented sustainable retrofitting strategies and their operational improvements, implementation costs, adaptability, technical complexity, and annual financial savings related information.

Interviews with Decision Makers – Another set of focused group discussions were held with decision-makers in hotel operation such as Finance Managers, General Managers, CEOs, and Operation Managers. These discussions aim to identify the factors related to the implementation of retrofits, and improvements in systems to optimize performance. Decision-makers in the hotels such as Finance Managers, CEOs, Directors, and Operation Managers were selected for focused group discussions to identify the factors of concern when making decisions related to new implementations and investments in the hotel.

- Selection of AHP as the Decision Support Framework

Based on the inputs from the data collection process, several retrofitting strategies were identified as mostly implemented strategies. Those strategies were further analyzed to establish a link between annual savings, financial feasibility and impact on the environment identifying the emission-saving potential. The concerns and criteria highlighted during the discussions were incorporated into a multicriteria decision-making analysis using the Analytical Hierarchy Process (AHP). AHP was selected over many others due to its systematic and structured approach that enables the evaluation of complex decisions involving multiple criteria. Since it breaks down the complex decision-making problem into a hierarchy of simpler subproblems and then allows for a comprehensive analysis of various factors; both qualitative and quantitative factors. Related to this particular assessment, this incorporates tuantitative factors such as annual emissions saving and initial investment and qualitative factors such as maintenance requiremsent and technical complexity. Further, using the pairwise comparison technique, AHP ensures that the relative importance of each criterion or factor is accurately assessed providing a robust framework for prioritizing retrofitting strategies based on their overall benefits. The use of the AHP method not only enhances the reliability of the decision-making process but also aligns with the diverse concerns and criteria identified during expert consultations and stakeholder discussions. Further, this ensures a balanced and well-informed evaluation of sustainable retrofits. [49]

3.4. Retrofit Identification & Analysis

The identification and analysis of retrofitting strategies involved with ailed and systematic approach incorporating inputs from a wide range of industry experts and leveraging robust analytical methods to ensure the selected strategies are both effective and feasible. This section outlines the key steps in this process, highlighting the considerations.

3.4.1. Retrofit Identification

Retrofit Identification was done based on two approaches: expert consultations and literature review. As mentioned in the previous section, the data collection process involved interviews or focused group discussions with industry experts. Energy management experts provided insights into energy-saving technologies and practices to reduce consumption and improve efficiency. Water conservation specialists offered strategies commonly implemented water reduction strategies and wastewater management strategies. Waste Management professionals discussed methods for minimizing waste generation and improving recycling rates. Experts in carbon accounting provided techniques for tracking and reducing emissions. Hotel management and finance professionals discussed the operational aspects of implementing each sustainable strategy. Their concerns were used for selecting decision making criteria in the Analytical Hierarchy Process.

Apart from the expert consultation sessions, the literature review was supported to identify calculated savings in each strategy selected based on proven effectiveness, feasibility and scalability. As a major reference followed in the study, The Net Zero pathway to the global accommodation sector highlights the key retrofitting strategies based on the implementation rates at different sized hotels. That was also considered when finalizing the related strategies implementable at Sri Lankan hotels. [50]. Thus, the selected retrofits are as follows.

ENERGY RETROFITS

a. **Lighting System Upgrad**e

- Replace inefficient lighting fixtures with LEDs
- Install dimmers
- Install motion sensors
- Daylight integration

b. HVAC System Upgrade

- Convert to inverter AC units
- Demand Controlled Ventilation

c. **Building Envelop Improvement**

- Green wall and roof
- Cool roof (White Paint)
- Blinds and curtains and shading devices
- Window glass improvement

d. **Renewable Energy Integration**

- Solar panels
- Solar Water Heating System

e. **Other**

- Keycard switches
- Building Management System installation

WATER RETROFITS

a. **Water Fixture Improvements**

- Sensor Faucets
- Low flow toilets
- Low flow showerheads

b. **Other Water retrofits**

- Greywater recycling
- Rainwater harvesting
- Drip Irrigation System

WASTE REDUCTION RETROFITS

a. **Food Waste**

- Waste Management
- Composting
- Food Donation/ Piggery

b. **Paper Waste**

- Digital Transformation
- Invest in Recycling Station
- Deviate landfill waste to recycle

c. Plastic Waste

- Onsite Bottling Plant
- Refillable Toiletries
- Recycling instead of landfill

3.4.2. Retrofit Analysis

The selected retrofitting strategies were subjected to a thorough analytical process to evaluate their potential benefits and challenges. This involved the development of specific formulas and criteria for each strategy. The developed formulas were embedded in the calculation tool to identify project-specific savings.

Potential Savings (Energy, Water, Waste) were estimated using the developed formula which includes both direct savings and indirect savings. Strategies such as efficient LED lighting will directly reduce electricity consumption while strategies such as green roofs or improved windows will reduce cooling load and contribute energy consumption reduction indirectly.

Emission Reductions were calculated based on the potential reductions calculated above and using the same emission factors. Cost savings were also derived using the estimated energy, water and waste savings. Initial investments were identified using supplier information and industry consultation experts to calculate the payback period.

The level of complexity and the adaptability to the existing system were identified for each strategy to be involved in the decision matrix development. The criteria, level of complexity focused on the involvement of special equipment or expertise, and potential disruptions to hotel operations during installation. Maintenance requirement was also assessed under each strategy.

The developed formula and criteria were embedded in the calculation tool designed to provide project specific analysis. The tool allowed for project specific inputs resulting in customized output. A walkthrough audit can be conducted prior entering data into this analysis identifying the quantities under each segment. Also, this tool enables comparative analysis of different strategies.

3.4.2.1 Energy Retrofit Analysis

In this section, the analysis of different energy retrofit strategies is presented. The selected retrofit strategies are as follows.

a. Lighting System Upgrade
    - Replace inefficient lighting fixtures with LEDs
    - Install dimmers
    - Install motion sensors
    - Daylight integration

b. HVAC System Upgrade
    - Convert to inverter AC units
    - Implement DCV system

c. Building Envelop Improvement
    - Green Wall and Roof
    - Cool Roof
    - Blinds and Curtains and Shading Devices
    - Window glass improvement

d. Renewable Energy Integration
    - Solar panels
    - Solar Water Heating System

e. Other
    - Keycard switches
    - BMS

Under each strategy, formulas were developed to calculate the following parameters.

a. Annual Energy Saving (kWh)
b. Annual Emissions Saving (kgCO_2e)
c. Annual Financial Saving (LKR)
d. Initial Investment (LKR)
e. Payback Period (PP)

Apart from the first parameter, the methodology and formulas are almost similar for all the energy saving retrofitting strategies. Those common formulas are Given in Equations 3-13 to 3-16.

$$Annual\ Emissions\ Saving\ \left(\frac{kgCO2e}{yr}\right) = Annual\ Energy\ Saving(kWh) \times Emission\ Factor\ \left(\frac{kgCO2e}{kWh}\right) \quad (3\text{-}13)$$

$$Annual\ Financial\ Saving\ (LKR/yr) = Annual\ Energy\ Saving(kWh) \times Unit\ Cost\ of\ Energy\left(\frac{LKR}{kWh}\right) \quad (3\text{-}14)$$

$$Initial\ Investment\ (LKR) = Unit\ Cost\ (LKR) \times Number\ of\ Units \quad (3\text{-}15)$$

$$Payback\ Period = \frac{Initial\ Investment\ (LKR)}{Annual\ Financial\ Saving\ (LKR/yr)} \quad (3\text{-}16)$$

Lighting System Upgrade

As first step one of the most trending energies saving retrofitting strategy, Lighting System Upgrade can be introduced. Lighting is known as the second highest energy consuming source in a hotel after HVAC-related energy consumption contributing nearly 15%-30% of the total electricity consumption. [30] The lighting system can be upgraded by changing inefficient fixtures with LEDs, improving the lighting control system with Dimmers, Motion Sensors, Daylight integration etc. As mentioned earlier, this framework will depend on site-specific data and in this section, information required to estimate the potential savings after adopting each strategy is mentioned in Table 3-3. All the assumptions are based on the expert reviews taken from the interviews conducted and that the financial inputs are taken as per current market conditions. Therefore, the inputs should be updated as per the latest figures.

Table 3-3: Lighting System Upgrade related input data and made assumptions

	Lighting System Upgrade Strategy	**Input Data Required**	**Assumptions Made**
E1.1	Replace inefficient fixtures with LED	Inefficient fixture details – rooms and common areas separately (Count, Wattages)	Average operating hours in rooms were taken as 4-6 hours and 24 hours in common areas
E1.2	Install Dimmers	Number of fixtures to install dimmers, full wattage	50% dimming was considered and average dimming hours were considered as 6 hours
E1.3	Motion Sensors	Number of fixtures to install motion sensors and their wattages	Switched off due to motion sensors per day was considered as 3 hours
E1.4	Daylight integration	Number of fixtures to install daylight sensors, their wattages	Switched off due to daylight sensors per day was considered as 5 hours

Energy Saving formulas for lighting system upgrade were integrated into the framework as given in Equations 3-17 to 3-20.

$$E1.1 = N_{11} \times [W_{NLED} - W_{LED}] \times T \times A_{occ} \times 365 \times \frac{1}{1000} \quad (3\text{-}17)$$

E1.1	=	Annual Energy Saving through replacing non-LEDs with LED (kWh)
N_{11}	=	Number of non-efficient non-LED fixtures
W_{NLED}	=	Wattage of inefficient non-LED fixture (W)
W_{LED}	=	Wattage of Equivalent LED fixture (W)
T	=	Daily operating hours (h)
A_{occ}	=	Average Annual Occupancy Rate (%)

$$E1.2 = N_{12} \times [FW - DW] \times T \times DH \times 365 \times \frac{1}{1000} \quad (3\text{-}18)$$

E1.2	=	Annual Energy Saving through installing Dimmers (kWh)
N_{12}	=	Number of Dimmers to install
FW	=	Full lighting wattage (W)
DW	=	Wattage when dimming (W)
T	=	Daily Operating Hours (h)
DH	=	Dimmable hours (h)

$$E1.3 = N_{13} \times W \times T_0 \times 365 \times \frac{1}{1000} \quad (3\text{-}19)$$

E1.3	=	Annual Energy Saving Through Motion Sensors (kWh)
N_{13}	=	Number of Motion Sensors installed
W	=	Fixture Wattage (W)
T_0	=	Daily switched off hours due to sensors (h)

$$E1.4 = N_{14} \times W \times T_0 \times 365 \times \frac{1}{1000} \quad (3\text{-}20)$$

E1.4	=	Annual Energy Saving Through Daylight Sensors (kWh)
N_{14}	=	Number of Daylight Sensors installed
W	=	Fixture Wattage (W)
T_0	=	Daily switched off hours due to sensors (h)

HVAC System Upgrade

Since over 50% of the total electricity consumption is contributed by the HVAC system of a hotel [32]. Therefore, HVAC system related improvements are essential for energy saving. According to the focused group discussions and data collection process of the sample hotels, it was observed that most of the small to medium type hotels have installed split type air conditioner systems considering factors such as reduced maintenance cost and lesser complexity of the operation. The strategies were selected based on those facts and the input data required for the analysis are given in Table 3-4.

Table 3-4: HVAC System Upgrade related input data and made assumptions

	HVAC System Upgrade Strategy	**Input Data Required**	**Assumptions made**
E2.1	Replace inefficient ACs with inverter types	Number of replacing units Cooling Capacity	• Average operating hours were considered as 12 hours • 35% Energy Saving was considered [51]
E2.3	Implement Demand Control Ventilation	Number of upgrading units Cooling Capacity	• Average operating hours were considered as 12 hours • 15% Energy Saving was considered [52]

Energy Saving formulas for HVAC system upgrades were integrated in the framework as per Equation 3-21 to Equation 3-23.

$$E2.1 = N_{21} \times P_h \times T \times A_{occ} \times 365 \times \frac{0.35}{1000} \tag{3-21}$$

E2.1	=	Annual Energy Saving through replacing non-Inverter ACs with Inverter ACs (kWh)
N_{21}	=	Number of non-inverter ACs to be replaced
P_h	=	Average hourly Power Consumption (W)
T	=	Daily operating hours (h)
A_{occ}	=	Average Annual Occupancy Rate (%)

$$E2.3 = N_{23} \times P_h \times T \times A_{occ} \times 365 \times \frac{0.15}{1000} \quad (3\text{-}22)$$

E2.3	=	Annual Energy Saving though DCVs (kWh)
N_{23}	=	Number of units to upgrade
P_h	=	Average hourly Power Consumption (W)
T	=	Daily Operating Hours (h)
A_{occ}	=	Average Annual Occupancy Rate (%)

Envelop Improvement

The envelop improvement has been identified as an important retrofitting strategy to achieve drastic energy savings through cooling load reduction. Different strategies are evaluated based on the input data provided related to the assessing hotel. Those required data and assumptions made in developing a formula for calculating the energy savings is as per Table 3-5.

Table 3-5: Envelop Improvement Strategy related input data and made assumptions

	Envelop Improvement Strategy	**Required Data**	**Assumptions**
E3.1	Green Walls and Roofs	Area of sun exposed walls and roofs	• Average ΔU values were considered for roof, wall as 3.232 W/m²K and 2.597 W/m²K [53]

			• Considered temperature difference of 8 degrees between indoor and outdoor • Assumed the AC unit COP as 3.5 • Assumed 12-hour operation per day
E3.2	Cool Roofs	Area of sun exposed roofs	• Average ΔU values were considered for roof as 3.232 W/m^2K • Considered temperature difference of 8 degrees between indoor and outdoor • Assumed the AC unit COP as 3.5 • Assumed 12-hour operation per day • Considered the 13% Saving [54]
E3.3	External Shading Devices	Number room guest rooms with sun exposed windows	• Average U value of single glazed window was considered as 4.5 • Considered 23% saving [55]
E3.4	Glazing Improvement	Number room guest rooms with sun exposed windows	• Average U value of single glazed window was considered as 4.5 W/m^2K • Considered 8% saving [56]

Energy-saving formulas for envelop improvement were integrated into the framework as per Equation 3-25 to Equation 3-28.

$$E3.1 = A \times [U_{Conv} - U_{Er.G}] \times \Delta T \times A_{occ} \times T_D \times 365 \times \frac{1}{(COP \times 1000)} \quad (3\text{-}23)$$

E3.1	=	Annual Energy Saving through green walls (kWh)
A	=	Sun Exposed Wall Area (m^2)
U_{Conv}	=	Average U value of existing wall (W/m^2K)
$U_{Er.G}$	=	Average U value of green wall (W/m^2K)
ΔT	=	Temperature Difference (K)
A_{occ}	=	Average Annual Occupancy Rate (%)
T_D	=	Daily AC operating hours (h)
COP	=	Coefficient of Performance of HVAC system

$$E3.2 = A \times U_{rf} \times \Delta T \times A_{occ} \times T_D \times 365 \times \frac{0.13}{(COP \times 1000)} \quad (3\text{-}24)$$

E3.2	=	Annual Energy Saving through Cool Roof (kWh)
A	=	Sun Exposed Roof Area (m^2)
U_{rf}	=	Average U value of existing roof (W/m^2K)
ΔT	=	Temperature Difference (K)
A_{occ}	=	Average Annual Occupancy Rate (%)
T_D	=	Daily AC operating hours (h)
COP	=	Coefficient of Performance of HVAC system

$$E3.3 = A \times U_{rf} \times \Delta T \times A_{occ} \times T_D \times 365 \times \frac{0.23}{(COP \times 1000)} \quad (3\text{-}25)$$

E3.3	=	Annual Energy Saving through External Shading Devices (kWh)
A	=	Sun Exposed Window Area (m^2)
U_{rf}	=	Average U value of existing window (W/m^2K)
ΔT	=	Temperature Difference (K)
A_{occ}	=	Average Annual Occupancy Rate (%)
T_D	=	Daily AC operating hours (h)
COP	=	Coefficient of Performance of HVAC system

$$E3.4 = A \times U_{rf} \times \Delta T \times A_{occ} \times T_D \times 365 \times \frac{0.08}{(COP \times 1000)} \quad (3\text{-}26)$$

E3.4	=	Annual Energy Saving through Glazing Improvement (kWh)
A	=	Sun Exposed Window Area (m^2)
U_{rf}	=	Average U value of existing window (W/m^2K)
ΔT	=	Temperature Difference (K)
A_{occ}	=	Average Annual Occupancy Rate (%)
T_D	=	Daily AC operating hours (h)
COP	=	Coefficient of Performance of HVAC system

Renewable Energy Integration

Renewable energy integration is one of the key strategies to save energy as well as trending retrofitting techniques used by many hotels nowadays. The investment decision has been made easy with the reducing market prices of the solar panels. Anyway, the required information for estimating the energy generation potential and determining the required size of the project are mentioned in Table 3-6.

Table 3-6: Renewable Energy Integration related input data and made assumptions

	Strategy	**Required Data**	**Assumptions**
E4.1	Solar Panel Installation	Effective area of roof Annual energy demand	• Considered 560W panels • Solar generation period considered as 4 h
E4.2	Solar Water Heaters	Area of sun exposed roofs	• Hot water usage per guest per day was taken as 150 liters/day [57] • Guests per room was taken as 2 • Solar Fraction was taken as 0.6

Energy-saving formulas for renewable energy integration were integrated into the framework are as per Equation 3-29 to Equation 3-32.

$$E4.1 = N_{SP} \times PP \times 0.8 \times T_D \times 365 \times \frac{1}{1000} \quad (3\text{-}27)$$

E4.1	=	Annual Energy Saving through Solar Electricity generation (kWh)
N_{SP}	=	Number of Installable Solar Panels
PP	=	Panel Power (W)
T_D	=	Daily AC operating hours (h)

$$N_{SP} = A_{E.roof} \times \frac{0.67}{A_P} \quad (3\text{-}28)$$

N_{SP}	=	Number of Installable Solar Panels
$A_{E.roof}$	=	Effective Roof Area (Sq ft)
A_P	=	Area of a Solar Panel (Sq ft) – (Taken as 27 sq ft)

$$E4.2 = [HW_D \times D] \times C \times \Delta T \times SF \times 365 \times \frac{1}{3600} \quad (3\text{-}29)$$

E4.2	=	Annual Energy Saving through Solar Hot Water System (kWh)
HW_D	=	Daily Hot Water Demand (liters)
D	=	Density of Hot Water (kg/liter)
C	=	Specific Heat Capacity
ΔT	=	Temperature Difference (K)
SF	=	Solar Fraction

$$HW_D = A_{occ} \times R \times G \times V \quad (3\text{-}30)$$

HW_D	=	Daily Hot Water demand (Liters/Day)
A_{occ}	=	Average Annual Occupancy Rate (%)
R	=	Number of rooms
G	=	Guests per room
V	=	Hot Water Usage per guest (Liters/Day)

Other Energy Retrofits

Apart from the above retrofits, the two key retrofits mentioned in Table 3-7 were also analyzed under this study. Considered assumptions and required data are mentioned in the Table 3-7.

Table 3-7: Other energy related retrofit strategies related input data and made assumptions

	Strategy	Required Data	Assumptions
E5.1	Key Card Switches	Number of unoccupied hours Hotel occupancy	• Assumed 2 hours of non-occupancy • Assumed only saving from the air conditioner and lights
E5.2	BMS Installation	Annual energy demand	• 2% of energy demand will be saved through BMS (lighting control) [58]

Equation 3-33 and Equation 3-34 are the formulas embedded in the framework related to above considered other retrofitting strategies.

$$E5.1 = T_{Uocc} \times E_R \times A_{occc} \times R \times 365 \times \frac{1}{1000} \quad (3\text{-}31)$$

E5.1	=	Annual Energy Saving through key card switches (kWh)
T_{Uocc}	=	Time of unoccupancy during the stay (Per room) (h)
E_R	=	Energy Consumption related to unoccupied hours (W)
A_{occ}	=	Annual occupancy (%)
R	=	Number of rooms

$$E5.2 = E_h \times 0.02 \quad (3\text{-}32)$$

$E5.2$ = Annual Energy Saving through BMS (kWh)

E_h = Annual Energy demand of the hotel (kWh)

All those retrofit techniques are assessed based on the requirements of a given hotel giving the specialized inputs. The retrofit techniques are evaluated based on selected few criteria and ranked accordingly supporting decision-making on investment opportunities for going Net Zero with sustainable retrofits. The same methodology is followed for the water saving retrofits and waste minimization retrofits.

3.4.2.2. Water Saving retrofits

In this section, the analysis of different water retrofit strategies is presented. The selected retrofit strategies are as follows.

a. Water Fixture Improvements
    - Sensor faucets
    - Low flow toilets
    - Low flow showerheads
b. Other Water retrofits
    - Greywater recycling
    - Rainwater harvesting
    - Drip irrigation system

The following parameters were assessed regarding the above-mentioned strategies.

a. Annual Water Saving (m^3)
b. Annual Emissions Saving ($kgCO_2e$)
c. Annual Financial Saving (LKR)
d. Initial Investment (LKR)
e. Payback Period (Yrs)

The calculation formula for the last 4 parameters is the same as from Equation 3-13 to Equation 3-16.

Water Fixture Improvement

According to previous studies such as AIHE 1996, water consumption has been identified as a key component that contributes over 10% of the utility bills in a hotel. The location-wise water consumption analysis has shown that the hotel guest rooms contributed of 38% and the kitchen being the next highest contributor, with 21% of the total hotel water consumption. Public washrooms contribute 16% of the total water consumption in a hotel [32]. Therefore, the washroom fixture improvement will be a significantly impactful retrofitting action for water conservation. Accordingly, the following three strategies have been analyzed in the developed framework.

Water Saving calculations were done following the assumptions given in Table 3-8 and formula.

Table 3-8: Water Fixture improvement related input data and assumptions

	Water Fixture Improvements	**Input Data Required**	**Assumptions made**
WS1.1	Replace basin faucets with sensor faucets (Rooms and common areas)	Number of basin faucets to improve (Rooms and Common areas separate)	Normal tap flow rate was taken as 12 lpm and sensor tap flow rate was taken as 3 lpm Assumed 16 sec per wash (2.4 liter saving per wash) Assumed 2 guests per room and 5 times per day use per guest (rooms) once (common areas) [59]

WS1.2	Retrofit single flush toilets to dual flush	Number of toilets to improve (Rooms and Common areas separate)	Assumed the Improvement from 11 lpf to 3.5 lpf [59] Assumed 2 times per guest per day use (rooms) once per guest per day use (Common areas)
WS1.3	Retrofit showers with low flow shower heads	Number of showers to improve	Assumed 30 lpb to 11 lpb Assumed once per guest per day use [59]

To incorporate the water fixture improvements formulas given in Equation 3-33 to Equation 3-39 were embedded in the framework

$$WS1.1 = (WS_R + WS_C) \times \frac{1}{1000} \tag{3-33}$$

WS1.1 = Annual Water Saving through Sensor Faucets (m^3)

WS_R = Annual Water Saving in rooms (liters)

WS_C = Annual Water Saving in common areas (liters)

$$WS_R(or\ WS_C) = WS_G \times N_G \times N_W \times A_{occ} \times F \times 365 \tag{3-34}$$

WS_G = Water Saving per wash (liters)

N_G = Number of guests per room

N_W = Number of washes per day per guest (5 per room and 1 per common area)

A_{occ} = Annual occupancy rate (%)

F = Number of fixtures to improve

$$WS1.2 = (WS_R + WS_C) \times \frac{1}{1000} \tag{3-35}$$

WS1.2 = Annual Water Saving through Low flow Toilets (m^3)

WS_R	=	Annual Water Saving in rooms (liters)
WS_C	=	Annual Water Saving in common areas (liters)

$$WS_R(or\ WS_C) = WS_f \times N_G \times N_f \times A_{occ} \times F \times 365 \quad (3\text{-}36)$$

WS_f	=	Water Saving per flush (liters)
N_G	=	Number of guests per room
N_f	=	Number of flushes per day per guest (2 per room and 1 per common area)
A_{occ}	=	Annual occupancy rate (%)
F	=	Number of Toilet fittings to improve

$$WS1.3 = WS_b \times N_G \times N_W \times A_{occ} \times F \times 365) \times \frac{1}{1000} \quad (3\text{-}37)$$

$WS1.3$	=	Annual Water Saving through Low flow Showerheads (m^3)
WS_b	=	Water Saving per bath (liters)
N_G	=	Number of guests per room
N_W	=	Number of baths per day per guest
A_{occ}	=	Annual occupancy rate (%)
F	=	Number of shower fittings to improve

Other Water Efficiency retrofitting

Apart from fixture improvement following strategies were identified as key strategies implemented in the industry. Greywater recycling, rainwater harvesting, and drip irrigation systems were assessed accordingly. Since the water consumption is a huge component of a hotel, greywater recycling has been identified as a key strategy to minimize non-potable water demand in the hotel. Recycled water then be used for irrigation, vehicle washing etc. Rainwater harvesting is also an ideal solution to reduce the potable water demand. Well maintained landscaping is essential in a hotel even if it consumes significant volume of water for maintenance. Drip irrigation has been identified as an efficient way of watering reducing over 50% of water required when watering in conventional way. [58]

Further, Water Saving calculations were done according to the following assumptions mentioned in Table 3-9.

Table 3-9: Other water retrofits related input data and made assumptions

	Other Water Retrofits	**Input Data Required**	**Assumptions made**
WS2.1	Greywater Recycling	Annual water demand	• Assumed greywater generation is 80% of total water demand • Considered 30% recovery of water through greywater recycling [52]
WS2.2	Rainwater Harvesting	Annual water demand	• Assumed only the requirement for irrigation is recovered through rainwater harvesting • Annual water demand for irrigation was taken as 18% of total water demand [60]
WS2.3	Drip Irrigation	Annual Water Demand Required length of the system	• Annual water demand for irrigation was taken as 18% of total water demand • Considered 60% of saving

The formulas embedded in the framework to calculate the savings of other water fixtures were as per Equation 3-40 to Equation 3-42.

$$WS2.1 = WD_A \times 0.8 \times 0.3 \quad (3\text{-}38)$$

$WS2.1$	=	Annual Water Saving through Greywater Recycling (m^3)
WD_A	=	Annual water demand (m^3)

$$WS2.2 = WD_A \times 0.18 \quad (3\text{-}39)$$

$WS2.2$	=	Annual Water Saving through Rainwater Harvesting (m^3)
WD_A	=	Annual water demand (m^3)

$$WS2.3 = WD_A \times 0.18 \times 0.6 \quad (3\text{-}40)$$

$WS2.3$	=	Annual Water Saving through Drip Irrigation (m^3)
WD_A	=	Annual water demand (m^3)

3.4.2.3. Waste Reduction retrofits

Waste management in a hotel has been identified as a key challenge in the pathway to sustainability. In this study, the following main areas were assessed to quantify the potential savings.

a. Food Waste Management
    - Food waste reduction strategies
    - Disposal deviation from landfill to piggery
    - Disposal deviation from landfill to composting
b. Paper Waste Management
    - Digital Transformation
    - Invest in a paper recycling station
    - Disposal deviation from landfill to recycle
c. Polythene and Plastic Waste Management
    - Onsite bottling plant
    - Refillable toiletries instead of single-use items
    - Disposal deviation from landfill to recycle

Food Waste Management

Under the food waste management strategies, both waste reduction strategies and disposal strategies were assessed. The combined effect of the following food waste reduction strategies was considered. It was considered that those will contribute to 5% of waste reduction [61].

- Inventory management
- Menu planning
- Buffet management offering smaller servings
- Portion control
- Food waste tracking

The major concern of the next two strategies was the emissions reduction. Disposal method change results in emissions contribution to the total hotel carbon footprint.

Paper Waste Management

With evolving technology, it is essential to upgrade the systems to digital methods replacing traditional operational activities such as guest registration and marketing resources. It will not only give environmental and financial benefits but also attract eco-loving guests. Paper required for the general operations was estimated to take 5 papers per guest per day (Guest Registration) and 100 papers per room (housekeeping). This was based on inputs from hotel stakeholders. Investing in an onsite recycling plant will also be beneficial and attractive since it showcases the hotel's commitment to sustainability.

Polythene and Plastic Waste Management

Single use plastic and polythene package waste can be introduced as a major contributor to hotel waste generation. Also, the single use toiletries contribute to huge waste generation. As a common strategy, single use plastic bottles can be replaced with glass bottles. The water refilling can be done onsite. The toiletries can be replaced with branded refilling items which will reduce the plastic waste generation. Unavoidable waste can be recycled rather than sending to landfill reducing the emissions generation associated.

3.4.3. Multicriteria Decision Making Analysis

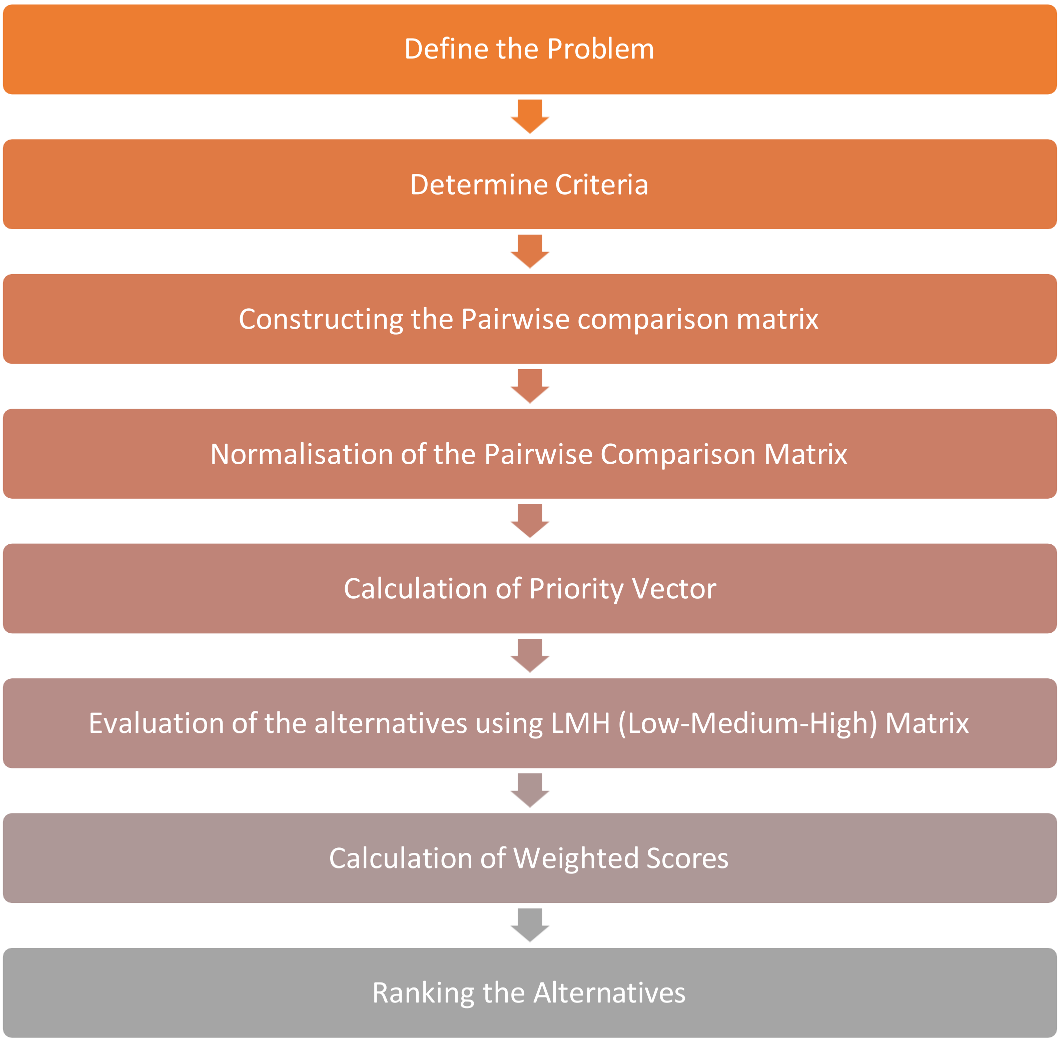

Figure 3-3: Multicriterial Decision Making Analysis Process

A multicriteria decision-making analysis was conducted using the Analytical Hierarchy Process (AHP), considering the multifaceted nature of this analysis to identify and prioritise sustainable retrofitting strategies for tourist and resort-type hotels . The AHP is a structures technique for organizing and analysing complex decisions, integrating both quantitative and qualitative criteria. The steps illustrated in Figure 3-3 outline the application of the AHP methodology in this study.

Step 1: Define the Problem

The primary goal of this research is to determine the most sustainable, hotel-specific retrofitting strategies for small to medium-sized tourist and resort-type hotels in Sri Lanka. Therefore, the Problem Statement is: "What are the optimal retrofitting Strategies that maximise sustainability while maintaining or improving hotel operations?".

Step 2: Determine Criteria

The following criteria were selected during the data collection and expert consultations are as follows and those were used to evaluate retrofitting strategies. According to the focused group discussions conducted with the hotel sector stakeholders such as Sri Lanka Tourism Development Authority (SLTDA) Professionals, Hotel Managers, Engineers, Sustainability Consultants, Sustainability Verifiers etc., it was identified that the selection of the optimum solutions to reduce GHG emission depends on various factors. There is common as well as unique factors of concern when implementing new strategies on the hotel premises. The multifaceted nature of these factors makes the AHP (Analytical Hierarchy Process) an ideal tool for evaluating and prioritizing different retrofit strategies based on their potential impact on different parameters or concerns.

Criteria Selection is a crucial step in this AHP Process since it involves identifying the factors affecting the decision-making process. With the objective of reducing the GHG emissions, the following criteria were selected based on stakeholder discussions and literature review.

a. Annual Emissions Saving (AES)
b. Initial Investment (II)
c. Maintenance Requirement (MR)
d. Payback Period (PP)
e. Technical Complexity (TC)
f. Adaptability to Existing System (AD)

The Annual emissions saving considers the potential GHG emission reduction achievable through the retrofit. Since the main goal is to target the Net Zero Hotel movement, emission reduction is the most important criterion. The second criterion is the common main concern in any type of investment. Since most of the companies have allocated budgets for the entire operation, it will be one of the key factors of concern in decision-making. Any addition may require a different level of maintenance. Adopting the lifecycle perspective of the decision, the maintenance requirement of the retrofit strategy is considered as a main criterion in decision making. In order to achieve the maximum out of the investment, having low payback periods is important. Therefore, as another factor of concern, the payback period has also been considered. Technical complexity is another factor of concern, which decides the personnel to be involved and the required level of training for the staff to implement and maintain the solution. As well as it covers the impact on the guests in case of supporting the initiative. The complexity matters when it is implemented, and guests are involved in the operation. The ability to integrate with the existing system is also a major concern, since any of the savings may not occur if it is hard to adapt to the existing system.

Therefore, the above-mentioned criteria were chosen to provide a comprehensive evaluation framework that considers financial, technical, and environmental aspects.

Step 3: Constructing the Pairwise Comparison Matrix

All the criteria were compared with each as pairs. For example, Annual Emissions Saving Potential and Initial Investment were compared and scored based on the AHP Pairwise comparison Scale given in Figure 3-4.

Numerical values	Description	Explanation
1	Equal importance of both elements	Two elements contribute equally
3	Moderate importance of one element over another	Experience and judgment favour one element over another
5	Strong importance of one element over another	An element is strongly favoured
7	Very importance of one element over another	An element is very strongly dominant
9	Extreme importance of one element over another	An element is favoured by at least on order of magnitude
2, 4, 6, 8	Intermediate values between two adjacent judgments	Used to compromise between two judgments

Figure 3-4: AHP Pairwise comparison scale

Each entry of the matrix $a_{i,j}$ represents the relative importance of Criterion F_i compared to Criterion F_j. The Matrix is outlined as per Table 3-10. Criteria of Annual Emissions Saving (AES), Initial Investment (II), Maintenance Requirement (MR), Payback Period (PP), Technical Complexity (TC), and Adaptability to Existing System (AD) were assessed in this process.

Table 3-10: Pairwise Comparison Matrix

	AES	II	MR	PP	TC	AD
AES	1	a_{12}	a_{13}	a_{14}	a_{15}	a_{16}
II	$\frac{1}{a_{12}}$	1	a_{23}	a_{24}	a_{25}	a_{26}
MR	$\frac{1}{a_{13}}$	$\frac{1}{a_{23}}$	1	a_{34}	a_{35}	a_{36}
PP	$\frac{1}{a_{14}}$	$\frac{1}{a_{24}}$	$\frac{1}{a_{34}}$	1	a_{45}	a_{46}
TC	$\frac{1}{a_{15}}$	$\frac{1}{a_{25}}$	$\frac{1}{a_{35}}$	$\frac{1}{a_{45}}$	1	a_{56}
AD	$\frac{1}{a_{16}}$	$\frac{1}{a_{26}}$	$\frac{1}{a_{36}}$	$\frac{1}{a_{46}}$	$\frac{1}{a_{56}}$	1

Step 4: Normalization of the Pairwise Comparison Matrix

Then the matrix was normalized by dividing each element by the sum of its column. The normalized matrix N is given by:

$$N = [\frac{a_{ij}}{\sum_{i=1}^{6} a_{ij}}] \quad (3\text{-}41)$$

Step 5: Calculation of Priority Vector

Priority Vector represents the weight of each criterion, and it was calculated by averaging the rows of the normalized matrix. The priority vector W is:

$$W = [w_1 \ w_2 \ w_3 \ w_4 \ w_5 \ w_6] \quad (3\text{-}42)$$

Step 6: Evaluation of Alternatives using LMH Matrix

Each retrofit strategy was evaluated against the criteria and the results were converted into a Low- Medium – High (LMH) scale. This qualitative assessment simplifies the analysis and categorizes each alternative's performance as given in Table 3-11 and the performance score (x_{ij}) are determined. For instance, Annual Emissions Saving (AES) is higher the better. Therefore, scores are defined for Low, Medium and High as 1,2 and 3. Similarly, the Initial Investment (II) is lower the better. Therefore, scores are defined as 3,2,1 for Low, Medium, and High Matrix development.

Table 3-11: Performance Scores for LMH Matrix

Criteria	Score - Low	Score - Medium	Score - High
AES	1	2	3
II	3	2	1
MR	3	2	1
PP	3	2	1
TC	3	2	1
AD	1	2	3

Step 7: Calculation of Weighted Scores

The weighted score S_i for each alternative A_i was calculated using the priority vector 'W' as per Equation 3-43.

$$S_i = \sum_{j=1}^{6} x_{ij} \cdot w_j \quad (3\text{-}43)$$

Step 8: Ranking the Alternatives

The alternatives were ranked based on their weighted scores. The alternatives with the highest weighted score were considered the most suitable retrofitting strategy.

This 8-step process was repeated for all the alternatives for Energy, Water and Waste Strategies separately. The combined ranking has also been performed separately.

3.5. Framework Development

The framework development phase is the integration of comprehensive data and insights obtained in earlier stages into a systematic structure. This phase aims to establish a robust and scalable framework to guide hotel stakeholders in the effective assessment and implementation of sustainable retrofit strategies. The development process incorporated several key elements.

a. Baseline performance evaluation over benchmarks
b. Potential retrofit evaluation
c. Retrofit prioritization
d. Implementation guidance

This step is to assess the current performance of the hotel in various sustainability metrics against established benchmarks. In the process, gathering relevant detailed data through the latest year is also supported. Accordingly, hotel's current energy consumption, water usage, waste generation are assessed. As another key activity, this step calculates the annual GHG emissions of the hotel. Further, comparing the data against industry standards and benchmarks and then identifying performance gaps is done at this step enabling to understand where the hotel stands in terms of sustainability and efficiency. As the final output from this step, provides a clear picture of potential improvement areas and sets a foundation for targeted interventions. In the next step, various retrofitting strategies are evaluated based on environmental performance, technical feasibility and financial feasibility to match the six criteria selected as the decision-making concerns. The following step prioritized the selected and evaluated retrofit strategies through AHP, the decision support framework selected for this particular study. The sub-steps of this process involve pairwise comparison matrix development and normalized matrix development which support prioritizing the level of significance of the selected decision-making criteria. Then, LMH Matrix is develop to take both quantitative and qualitative parameters onto a common measurable scale and finally the weighted matrix demonstrates the ranking of each strategy. As the final step of the framework, the implementation guidelines are provided to ensure the long-term sustainability of the selected top retrofits that were implemented or to be implemented.

By following the previous mentioned steps, the framework development phase ensures that the hotels can effectively identify, prioritize and implement sustainable retrofit strategies and further ensuring long term sustainability through provided guidelines. Thus, the outcome is a practical, and user-friendly framework that hotel operators can follow to systematically approach retrofitting projects ensuring consistency, and scalability aligning with sustainability objectives.

3.6. Guideline Development and Dissemination

The final step of the methodology is the Guideline Development and Dissemination aiming to extend the benefits of the development of this Strategic Framework, Guidelines and recommendations to a broader audience in Sri Lankan Hotel industry.

In this step, the guidelines will encapsulate the best practices identified in earlier steps and they will be more comprehensive, user- friendly and tailored to the specific needs and conditions in hotels in Sri Lanka. The findings from the retrofit evaluations and the decision support model were collated as best practices through detailed documentation for each retrofit strategy. Apart from that, templates for data entry, checklists, tables etc. are provided along with the developed strategic framework ensuring consistency and ease of use. Monitoring & performance tracking are extremely important to identify the actual reductions achieved through the implementation of the retrofits. Therefore, a separate guideline has been provided for post retrofit evaluations in order to validate the framework in the future and continuous improvement.

In this step, Sri Lankan Tourism Development Authority (SLTDA) will be involved to ensure effective communication and implementation across the sector, fostering a widened adoption of sustainable retrofitting solutions. An official endorsement from SLTDA will enable serious commitment from the hoteliers towards net zero through sustainable retrofitting guiding towards Net Zero transition of the industry. Most importantly, SLTDA will enable in establishing a robust feedback mechanism by collecting insights from user experience and emerged best practices via regular feedback sessions and surveys. It will enable continuous improvement and by allowing data sharing it will analyze key performance indicators and make necessary adjustments guiding the industry towards the right direction to achieve decarbonization goals. That ongoing continuous support and improvement process will be crucial in fostering an eco-conscious Hotel industry in Sri Lanka.

CHAPTER 4

4. Results and Discussion

This chapter focuses on the development of benchmarks for sustainable hotel buildings in Sri Lanka through sample analysis and assessing the results obtained through the developed Strategic Decision Framework. The analysis is based on input data provided by hotels and industry experts covering the three main areas: Energy retrofits, Water retrofits and waste management strategies. Each of the sections will outline the potential retrofits, expected savings, environmental impact, feasibility of implementing etc., that enable to select the optimum strategies to implement as retrofitting.

4.1. Sample Analysis for Benchmark Setting

According to the focus of the research, the selection of the hotel was based on the hotel's commitment to sustainability. Accordingly, 18 hotels were selected as the sample, covering most of the areas in Sri Lanka. The location map and summary of hotels are as given in Figure 4-1 and Table 4-1

Figure 4-1: Location Summary of The Sample Hotels

Table 4-1: Hotel Details of the selected sample

	Location	Rooms Count	Average Monthly Occupancy Rate (%)	Annual Occupied Rooms (2023)
1	Beruwala	199	80.8%	58,690
2	Trincomalee	81	72.9%	21,556
3	Kandy	119	58.1%	25,246
4	Bentota	155	39.7%	22,420
5	Yala	67	37.2%	9,085
6	Habarana	138	50.9%	25,646
7	Hikkaduwa	150	87.2%	47,720
8	Habarana	108	52.5%	20,694
9	Sigiriya	30	56.0%	6,132
10	Colombo 03	31	56.0%	6,326
11	Kalutara	156	83.0%	47,247
12	Anuradhapura	24	53.1%	4,648
13	Mirissa	130	74.0%	35,113
14	Kalutara	78	71.0%	20,214
15	Hikkaduwa	120	57.0%	24,966
16	Galle	150	38.0%	20,805
17	Negombo	65	65.0%	15,421
18	Anuradhapura	140	48.0%	24,528

4.1.1. Baseline Performance Analysis

This section focused on the overall analysis of the sample selected. Emissions were calculated for each hotel selected and a benchmark was identified for the industry performance. It was useful to identify the hotel operation and the contribution of each activity to the total carbon footprint.

Analysis was conducted to identify the scope-wise emissions, source-wise emissions and the energy balance of the hotels.

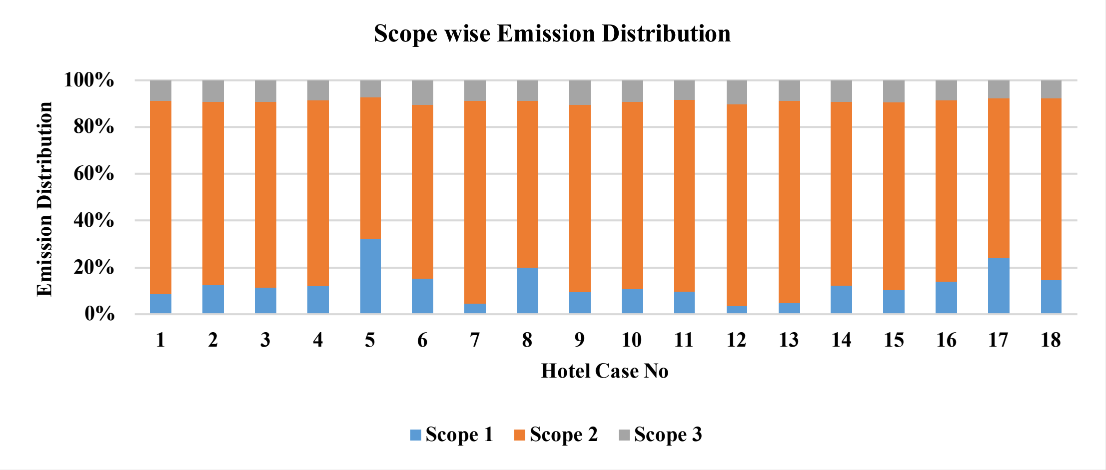

Figure 4-2: Scope Wise Emissions Distribution of sample hotels

As shown in Figure 4-2 majority of the emissions are from Purchased electricity under Scope 2 accounting for an average of 79% of the total emissions. 12% of the emissions are from Scope 1 and the rest of the emissions accounting for 9% of the total emissions are from Scope 3.

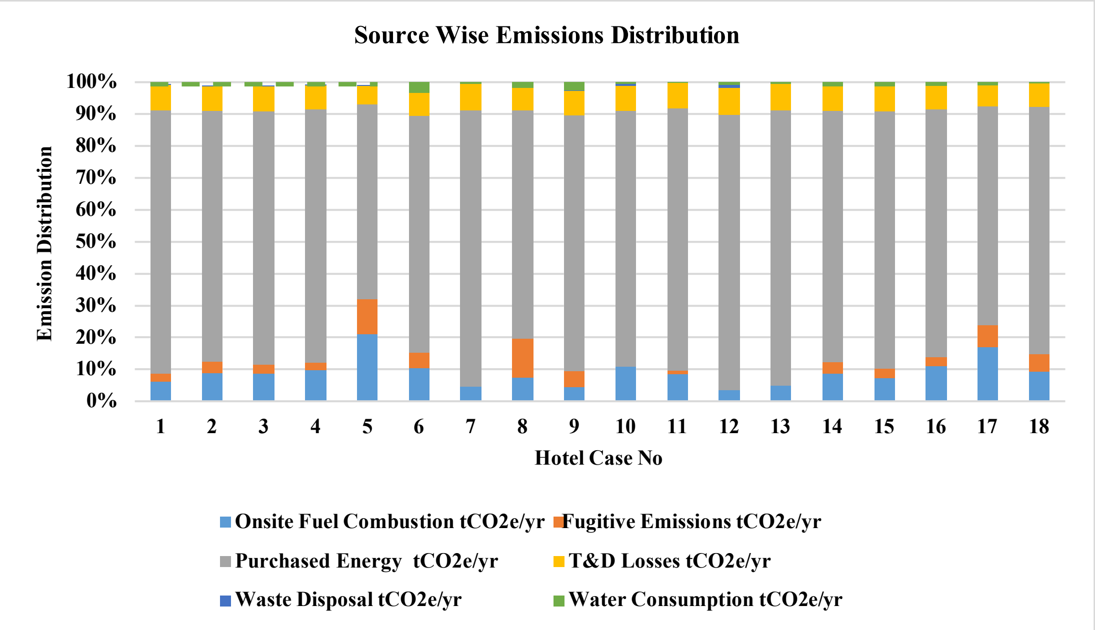

Figure 4-3: Source Wise Emissions Distribution of sample hotels

As illustrated in Figure 4-3 the highest contributing emission source is Purchased electricity with average of 79% of total emissions. Being the second highest contributor, onsite fuel combustion sources such as diesel and LPG account for 8.5% of the total emissions. Fugitive emissions are also a significant emission source that contributes nearly 3.5% of the total emissions. Even if Water and Waste do not contribute much to emissions, there is a significant impact on operational costs.

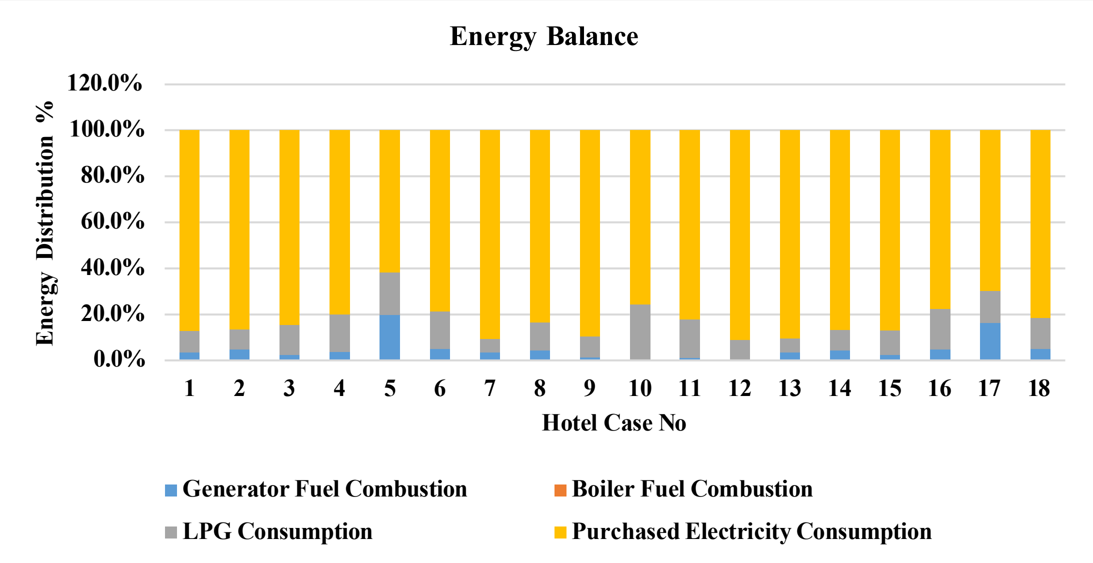

Figure 4-4: Energy balance summary of sample hotels

As illustrated in Figure 4-4, the main contributor to the energy balance of the hotels is electricity and it is followed by LPG consumption.

To effectively evaluate the sustainable performance of a hotel, it's required to establish relevant benchmarks or indicators. These indicators provide a means to measure, compare and track the progress over time. Related to hotels, these key performance indicators would be emissions per occupied room, electricity consumption per occupied room, water usage per occupied room and waste generation per occupied room.

Using these indicators "Per occupied room" offers several advantages over metrics such as "Per square feet" or "Per guest". Since it directly correlates with a hotel's primary operational focus, accommodating guests would provide a more relevant measure of performance. Also, the “Per occupied room” metric accurately reflects the dynamic nature of resource consumption in a hotel since it is closely tied to room occupancy than the total area or number of guests, whose individual behaviors vary significantly. Also, it facilitates the ability to compare the performance of different hotels regardless of the physical size. Also, the alignment of the financial metrics is also generated on a room basis, “per occupied room” metric will link the sustainability efforts with the profitability and investment justification.

4.1.2. Emissions per Occupied Room

According to the analysis, the Emissions per occupied room vary from 17.94 to 66.59 kgCO_2e/ Occupied room with an average value of 37.5 kgCO_2e/ Occupied room as illustrated in the Figure 4-5.

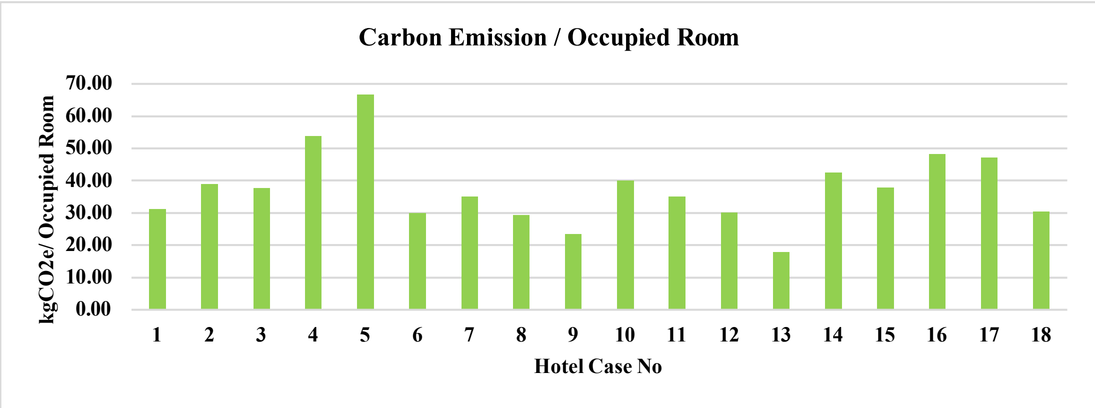

Figure 4-5: Carbon Emissions/Occupied Room in sample hotels

Electricity Consumption per Occupied Room - According to the data analysis results, the electricity consumption per occupied room varies from 36.19 to 99.84 kWh/ Occupied Room with an average value of 67.70 kWh/ Occupied Room as shown in Figure 4-6.

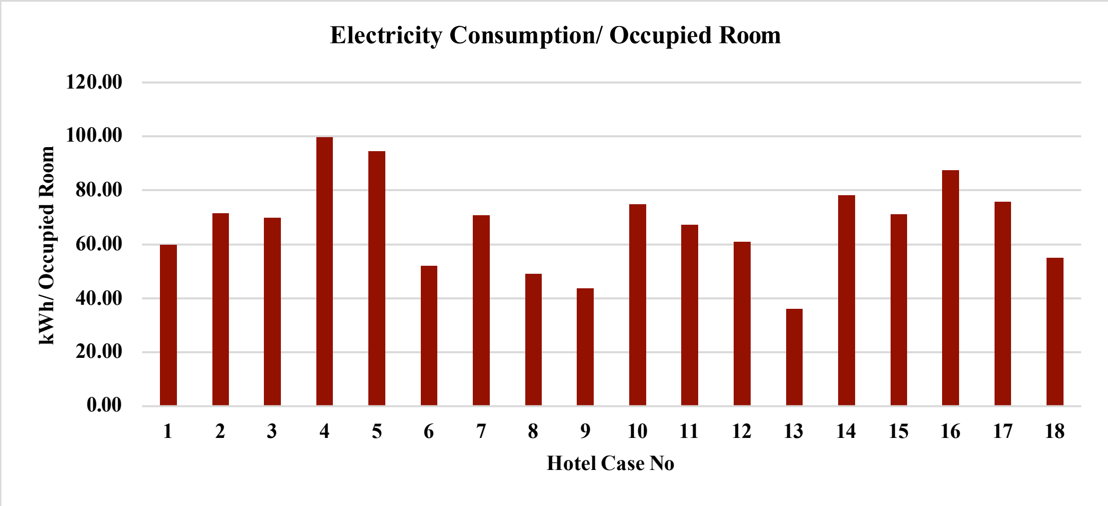

Figure 4-6: Electricity Consumption/Occupied Room in Sample Hotels

Water Consumption per Occupied Room - According to the data analysis results, the water consumption per occupied room varies from 0.4 to 6.58 m^3/ Occupied Room with an average value of 2.79 m^3/ Occupied Room as shown in Figure 4-7.

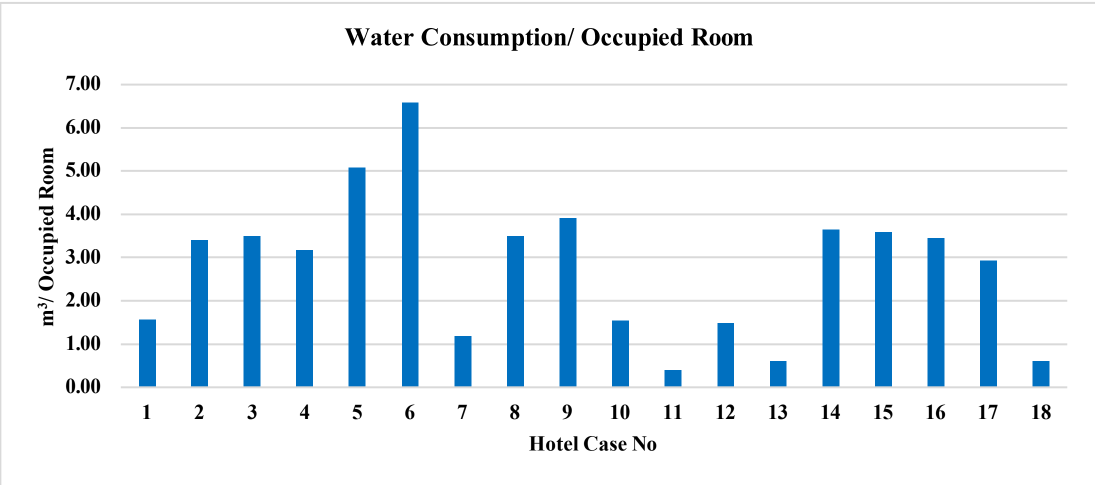

Figure 4-7: Water consumption/occupied room in sample hotels

Waste Generation per Occupied Room - According to the conducted data analysis results, the waste generation per occupied room varies from 0.57 to 14.34 kg/ Occupied Room with an average value of 4.13 kg/ Occupied Room as shown in Figure 4-8.

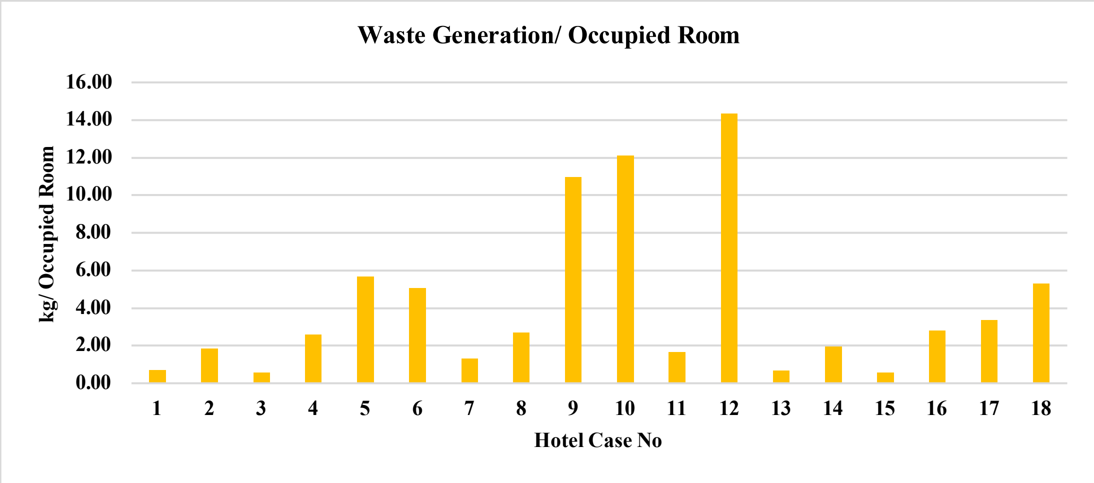

Figure 4-8: Waste generation/occupied room in sample hotels

4.1.3. Industry Benchmarks

To gauge the sustainability performance of hotels, it is important to consider the benchmarks established through internationally recognized studies and industry collaborations. The Cornell Hotel Sustainability Benchmark Index (CHSBI) is such system that provides comprehensive data on energy, Water and carbon performance based on over 25000 hotels globally. According to its latest report (2023) [62], the average energy consumption of the type of hotel considered in this study varies from 15 to 100 kwh/ Occupied room with an average of 57.5 kWh/ Occupied Room. Water Usage ranges from 0.03 to 0.95 m^3/ Occupied room (Average 0.49 m^3/ Occupied room) in such hotels without an inhouse laundry facility and 0.02 to 1 m^3/ Occupied room (Average 0. 51 m^3/ Occupied room) with an in-house laundry facility. According to the Sustainability Hospitality Alliance and a few other references, the waste generation in this type of hotel is around 1.78 kg/Occupied Room. Summarized average figures are as per Table 4-2.

Table 4-2: Benchmark Comparison

Area	International Benchmark (Average)	Local Benchmark (Analysis results)
Carbon Emission (kgCO2e/ Oc. room)	42	37.5

Energy Consumption (kWh/ Oc. Rm)	57.5	67.7
Water Consumption (m^3/Oc. Room)	0.49	2.79
Waste Generation (kg/ Oc. Room)	1.78	4.13

As shown in the above table comparison, Sri Lankan Hotels' average performance is somewhat lower than the global average. The retrofitting strategies can support achieving this by reducing the indicator values.

The comparison between local and international benchmarks reveals varied performance in sustainability metrics. The local carbon emissions per occupied room (37.5 $kgCO_2e$) are below the international benchmark (42 $kgCO_2e$), indicating effective carbon management practices locally. However, local energy consumption per occupied room is higher (67.7 kWh) than the international benchmark (57.5 kWh), suggesting inefficiencies that may stem from climate-specific needs or appliance performance differences. Water consumption exhibits a significant discrepancy, with local usage at 2.79 m^3 per occupied room compared to the international benchmark of 0.49 m^3, highlighting a possible lack of water conservation measures locally. Additionally, waste generation per occupied room in the local context is 4.13 kg, more than double the international benchmark of 1.78 kg, indicating room for improvement in waste management practices. Overall, while local carbon emissions align well with global standards, energy, water, and waste metrics suggest areas for targeted enhancements to better match international sustainability benchmarks.

4.2. Decision Support Model

4.2.1. Constructing the Pairwise Comparison Matrix

Depending on the insights received by the stakeholders and experts in related industries, a pairwise comparison was conducted for the selected decision criteria to identify the relative importance of each factor. According to the steps of the AHP, the next step is to develop the Pairwise Comparison Metrix. It allows a systematic comparison of each criterion relative to each other. This was developed based on the output from the focused group discussions conducted with the stakeholders. They were requested to scale ranges from 1 to 9 where 1 is 'equal importance' and 9 is extremely important'. For an example, if 'Annual Emissions Saving' is moderately more important than 'Initial Investment', 3 would be assigned in the matrix. Conversely, a reciprocal (1/3) would be assigned to the 'Initial investment' vs 'Annual Emissions Saving'. Likewise, this pairwise comparison allows to quantify subjective judgments, allowing for the construction of a numeric matrix that reflects the relative importance of each criterion. In this case a 6 by 6 matrix was developed in the process,. Using the insights through the surveys and focused group discussion results, Pairwise Comparison Matrix was developed as per Table 4-3.

Table 4-3: Pairwise Comparison Matrix

	AES	II	MR	PP	TC	AD
AES	1	2	4	6	5	3
II	1/2	1	2	3	4	1/2
MR	1/4	1/2	1	2	3	1/3
PP	1/6	1/3	1/2	1	2	1/4
TC	1/5	1/4	1/3	1/2	1	1/5
AD	1/3	2	3	4	5	1
TOTAL	**2.45**	**6.08**	**10.83**	**16.50**	**20**	**5.28**

4.2.2. Normalization and Priority Vector Calculation

The next step of the AHP Process after developing the pairwise comparison Matrix is normalization. It involves dividing each value in the matrix by the sum of its column. Through this step, it ensures that the comparisons are on a common scale. The normalized matrix is then used to calculate the priority vector which is done by averaging the values in each row of the normalized matrix. Such weight vectors or priority vectors indicate the importance given to each factor in the decision-making process. The matrix shown in Table 4-4 is the normalized matrix and the calculated priority vectors.

Table 4-4: Normalised Matrix and Priority Vectors

Normalised	AES	II	MR	PP	TC	AD	Priority Vector
AES	0.41	0.33	0.37	0.36	0.25	0.57	0.38
II	0.20	0.16	0.18	0.18	0.20	0.09	0.17
MR	0.10	0.08	0.09	0.12	0.15	0.06	0.10
PP	0.07	0.05	0.05	0.06	0.10	0.05	0.06
TC	0.08	0.04	0.03	0.03	0.05	0.04	0.05
AD	0.14	0.33	0.28	0.24	0.25	0.19	0.24

For an Example, AES-AES Cell value in Table 4-4 was determined by; AES - AES Cell (Table 4-4) / Total AES in Table 4-4. (1/2.45=0.41)

Accordingly, the priority of the factors is reduced as the following order.

1	Annual Emissions Saving (AES)	0.38
2	Adaptability to Existing System (AD)	0.24
3	Initial Investment (II)	0.17
4	Maintenance Requirement (MR)	0.10
5	Payback Period (PP)	0.06
6	Technical Complexity (TC)	0.05

4.3. The Framework Development

The framework development was carried out in 4 stages as explained in Figure 4-9.

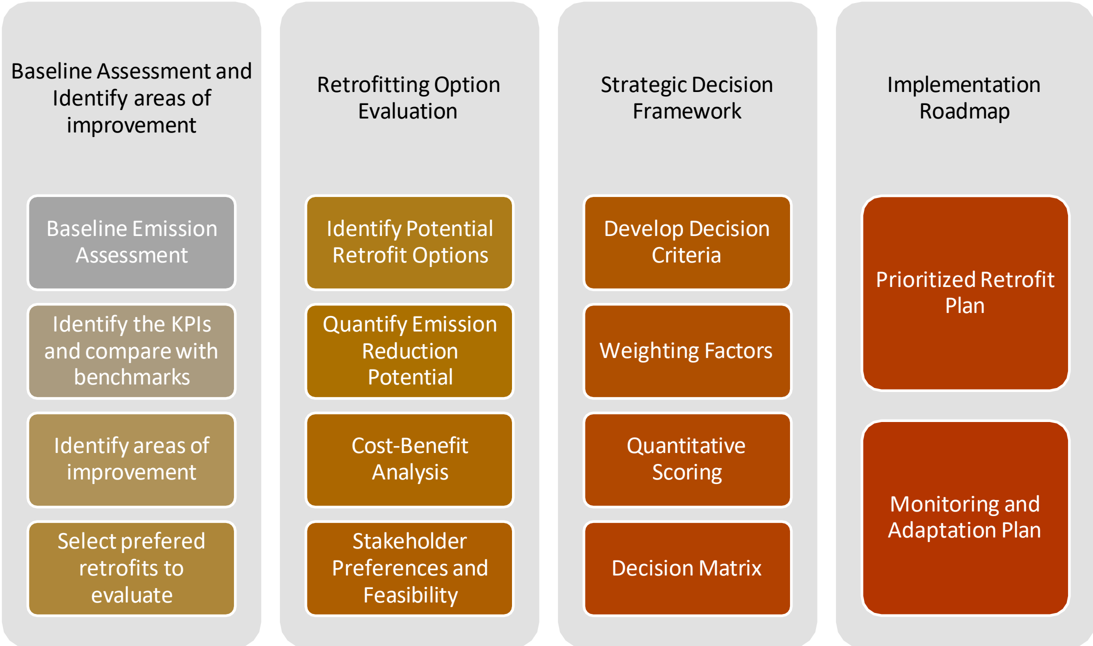

Figure 4-9: Outline of the Strategic Framework for Selection of Sustainable Retrofits

The developed framework involves four main steps: Baseline Assessment and identifying areas of improvement, Retrofitting Option Evaluation, Strategic Decision Framework and Implementation Road Map.

Step 1: Baseline Assessment and Identifying Areas of Improvement

The first step involves establishing a vivid understanding of the present environmental performance of the hotel. It consists of collection of data (Demographic information, energy, water and waste-related data), GHG Emission Calculation and comparison of the KPIs (Energy, water, waste and GHG Emissions per occupied room) with industry benchmarks revealing low performing areas for improvement. A graphical presentation of each result is also available under each table. All these three components are embedded in the "BASELINE ASSESSMENT" Tab in the excel based tool. Structure of the tab and guidelines for each component are as per Figure 4-10. Table numbers mentioned in the upcoming content will follow the outline demonstrated in Figure 4-10.

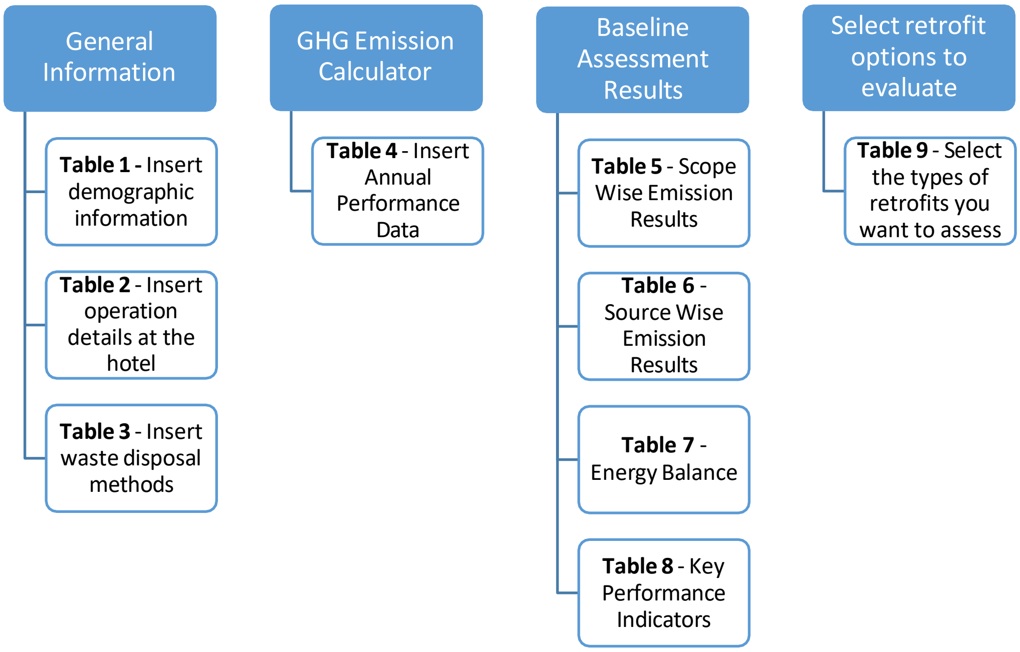

Figure 4-10: Outline of the 'BASELINE ASSESSMENT' Tab in the excel based framework

Step 2 – Retrofit Evaluation Figure 4-11 illustrates the outline of the Step 2.

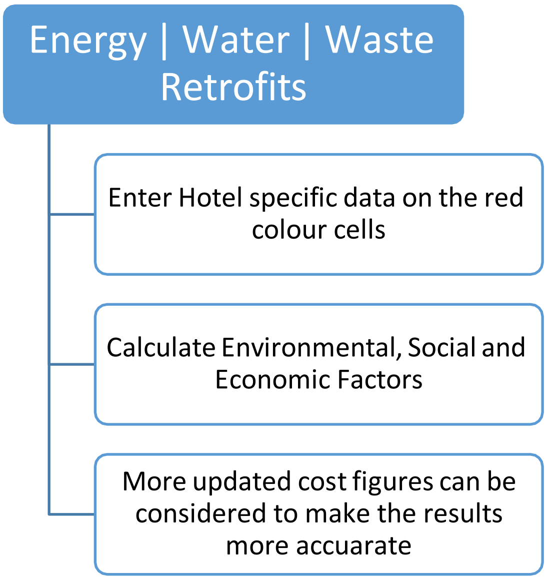

Figure 4-11: Outline of the 'ENERGY, WATER & WASTE RETROFITS' tabs in the excel based framework

This step consists of 3 sections separately presented in three tabs; Energy Retrofits, Water Retrofits and Waste Retrofits. In all three tabs, the selected options in

Table 9 in the first tab are analyzed to calculate environmental, social and economic factors; Annual Savings (Energy Saving, Water Saving or Waste Generation Reduction), Annual Financial Saving, Initial Investment and Payback Period. Data has to be entered only in the cells marked in red colour in the Energy/ Water/ Waste Retrofit Tabs (Refer to Figure 4-11), which depends on the selection of retrofits in Table 9 in the excel based framework (Refer to Figure 4-10). The cost of installation has been entered by default, but it is allowed to change at each cell since that is dependent on the market conditions. In these three tabs, there are 30 retrofits that have been embedded in this tool including 15 energy saving retrofits, 6 water saving retrofits and 9 waste reduction retrofits.

Step 3 – Strategic Decision Framework

The next phase involves developing a Decision Support Model to systematically assess and prioritize the retrofitting options selected in Table 9 (Refer to Figure 4-10). Decision criteria were selected as explained in a previous section considering cost, emission reduction potential, ease of implementation etc. Weighting factors were assigned to each criterion to reflect their relative importance using the Analytical Hierarchy Process (AHP) to ensure accuracy. (Table17- Refer to Figure 4-12) Then each of retrofit option is scored quantitatively against the selected criteria after LMH Ranking (Table 18-20 – Refer to Figure 4-12) resulting in a Comprehensive Decision Matrix showed in Table 21,22 and 23 (Refer to Figure 4-12). Finally, this matrix facilitates the ranking of each option based on this overall score guiding for the selection of the most effective and feasible retrofitting strategies.

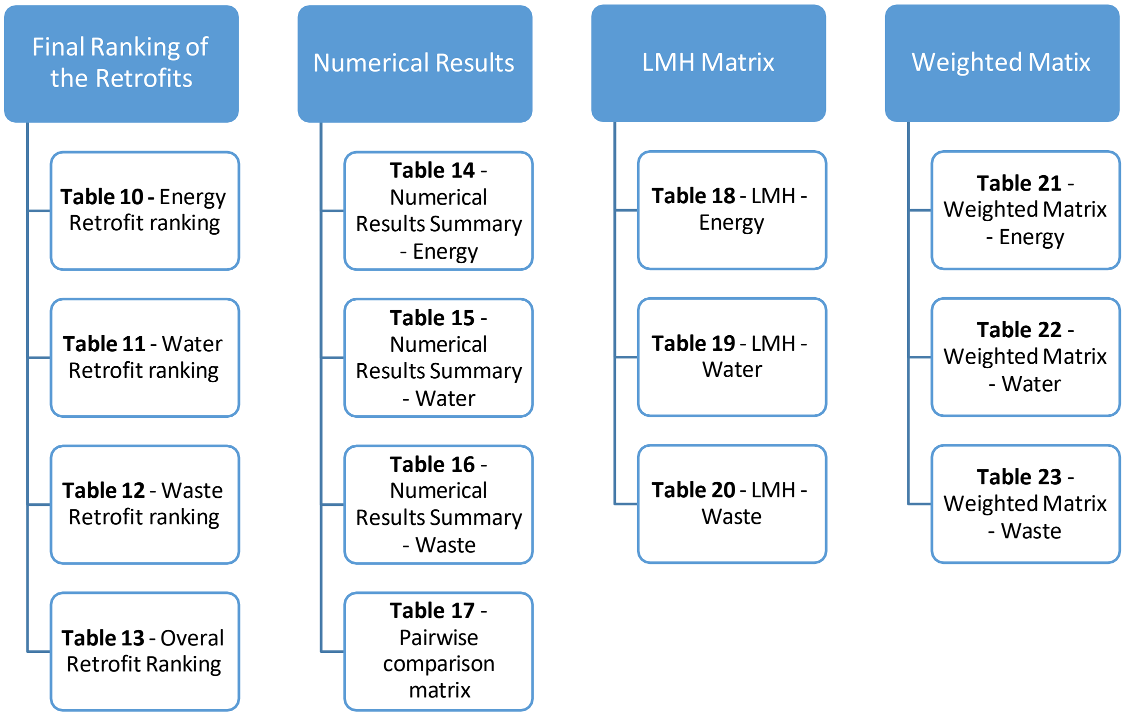

Figure 4-12: Outline of the “ANALYSIS RESULTS” Tab in the excel based framework

4.4. Case Study Analysis and Results

The developed strategic decision support framework can be discussed with the following hotel analysis. A hotel was selected for this analysis considering their commitment to environmental sustainability and their willingness to participate in this study, providing a practical case for testing the framework. Focusing on Baseline Assessment, retrofitting options evaluation, Decision Support and Implementation Planning, this study aims to identify opportunities for sustainable improvements and measure their impact in this hotel. The findings will provide a comprehensive understanding of the framework’s effectiveness and also will offer practical recommendations for broader application in the hotel industry.

4.4.1. Introduction to the Case Study

The selected hotel is a mid-sized tourist hotel located in the coastal zone of Trincomalee, Sri Lanka. It consists of 81 rooms with an annual average occupancy rate of nearly 73%. Further, as per Segment 1 in the "BASELINE ASSESSMENT", the Hotel Profile and other operational data are mentioned below.

Table 4-5: Case study hotel details

1	Name of the Hotel	CBB
2	Name of the Hotel Group	C
3	Address	Trincomalee
4	City	Trincomalee
5	Reporting Year	2023
6	Number of Guest Rooms	81
7	Average monthly occupancy rate (%)	72.90%
8	Total number of occupied rooms for the reporting year	21556
9	Gross floor area (sq ft)	

Table 4-6: General other details of the case study hotel

1	How is the laundry service occurred?	Outsourced
2	Annual laundry weight (Tonnes)	
3	Is there an onsite wastewater treatment plant within the premises	No
4	Have you ever conducted an energy audit?	No
5	Are you able to provide location wise average energy distribution?	No
6	What is the type of HVAC System used in the hotel	Split AC
7	Total annual cost of energy	57,085,339.00
8	Total annual cost of water	11,038,350.00
9	Total annual cost of LPG	3,212,640.00

Table 4-7: Waste Disposal methods of case study hotel

	Waste Types	**Select the Disposal Method**
1	Biodegradable waste (Food Waste)	**Piggery**

2	Paper and Cardboard	**Recycle**
3	Plastic and Polythene	**Recycle**
4	E waste	**Recycle**
5	Waste Oil	**Incineration**
6	Mixed Waste	**Landfill**
7	Garden Waste	**Not Applicable**

Methodology

Above mentioned details were collected using a survey form shared with the hotel team. Further, through the same sheet, energy consumption, water consumption and waste generation related data were collected for the period of 12 months (January 2023 to December 2023). The data entered and results obtained through the Carbon Calculation Tool as per Segment 2 in the "BASELINE ASSESSMENT" tab are as shown in Table 4-8.

Table 4-8: Carbon calculator – calculated the carbon emission

	Description	Activity Data	Unit	Annual Emission (tCO_2e)
Scope 1	**Direct GHG Emissions - Onsite**			
1	Annual Diesel consumption (Generators)	**8,757.64**	Liters	23.290
2	Annual Diesel consumption (Mobile)		Liters	0.000
3	Annual LPG Consumption	**10.35**	Tonnes	30.422
4	Annual Petrol Consumption	**8,871.80**	Liters	20.805
5	Annual Fuelwood Consumption (Biomass Boiler if available)	**0.00**	Tonnes	0.000
6	Annual Refrigerant gas refilling - R22	**4.11**	kg	7.234
7	Annual Refrigerant gas refilling - R32	**0.00**	kg	0.000
8	Annual Refrigerant gas refilling - R134a	**2.50**	kg	3.250
9	Annual Refrigerant gas refilling - R410	**10.74**	kg	20.664
10	Annual Fire Extinguisher refilling - CO_2	**0.00**	kg	0.000

Scope 2	Indirect GHG Emissions from Energy Use - Purchased Electricity

11	Annual Purchased Electricity Consumption - Hotel	**1,542,847.00**	kWh	660.030
12	Annual Purchased Electricity Consumption - Laundry Service	**15,428.47**	kWh	6.600

Scope 3	Indirect GHG Emissions - Supply Chain

13	Annual T&D Losses	**150,359.91**	kWh	64.324
14	Annual Biodegradable waste	**37.32**	Tonnes	0.000
15	Annual Paper and Cardboard waste	**1.15**	Tonnes	0.024
16	Annual plastic & Polythene waste	**0.96**	Tonnes	0.020
17	Annual E waste	**0.00**	Tonnes	0.000
18	Annual Waste Oil	**0.00**	Tonnes	0.000
19	Annual Mixed waste (other)	**0.00**	Tonnes	0.000
20	Annual Garden waste	**0.00**	Tonnes	0.000
21	Annual Water Consumption - Hotel	**73,589.00**	m^3	11.018
22	Annual Water Consumption - Laundry Service	**735.89**	m^3	0.110
	Total Carbon Footprint (tCO_2e/yr)			**847.79**

STEP 1: BASELINE ASSESSMENT

GHG Emission Results

As per Segment 3 of the "BASELINE ASSESSMENT" tab, the Scope Wise and Source wise Emission Results are given in Figure 4-13 and Figure 4-14.

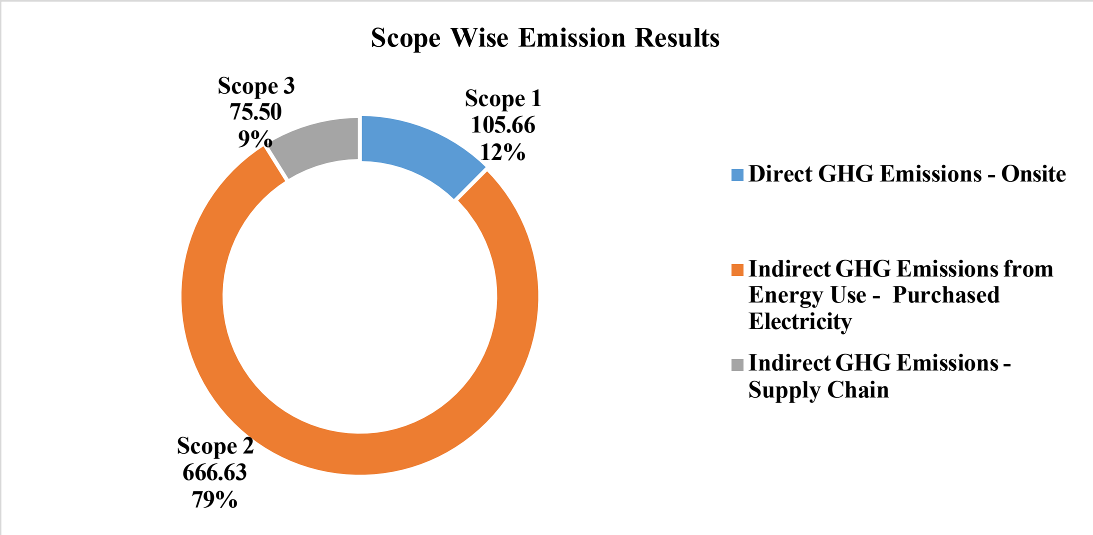

Figure 4-13: Scope wise emission results of the case study hotel

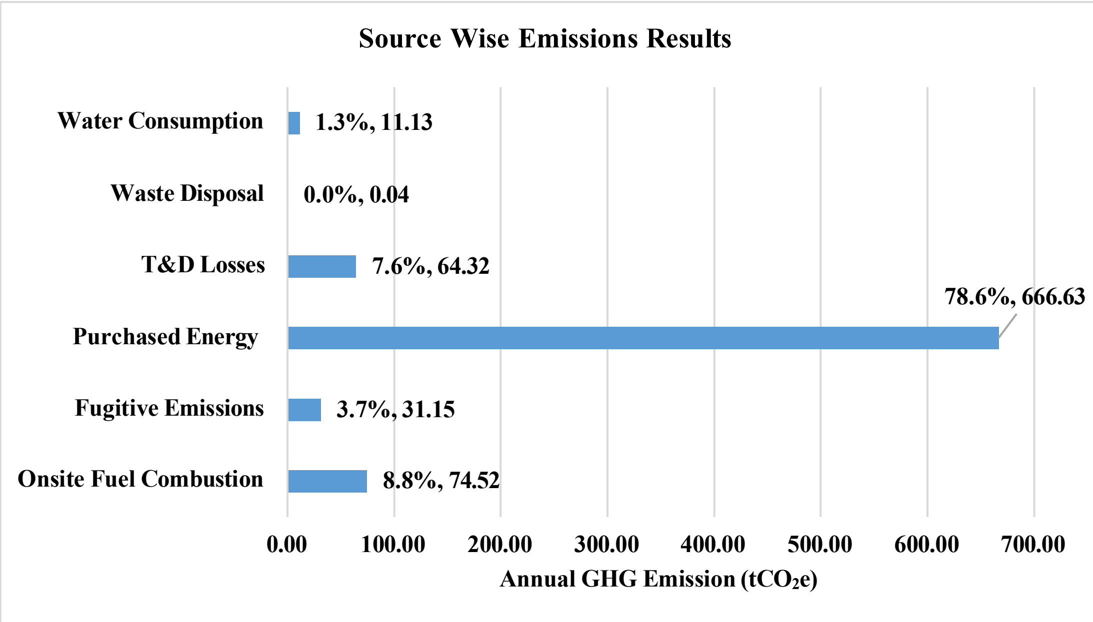

Figure 4-14: Source wise emissions results of the case study hotel

As shown in Figure 4-13, majority of the emissions are from Scope 2, purchased electricity contributing 79% of the total carbon footprint. Referring to Figure 4-14, the second highest emission source is onsite fuel combustion which is from generator fuel and petrol combustion contributing to 8.8% of the total emission.

Energy Performance

As shown in Figure 4-15, the energy balance of the hotel is dominated by the electricity consumption contributing 87% of the energy consumption in the hotel premises. LPG Consumption contributes 9% of the hotel's energy consumption while generator fuel contributes only 4% of the total energy consumption. Finally, as a key insight, it is clear that the high reliance on purchased electricity has the potential for significant energy savings through energy efficiency measures and renewable energy installation.

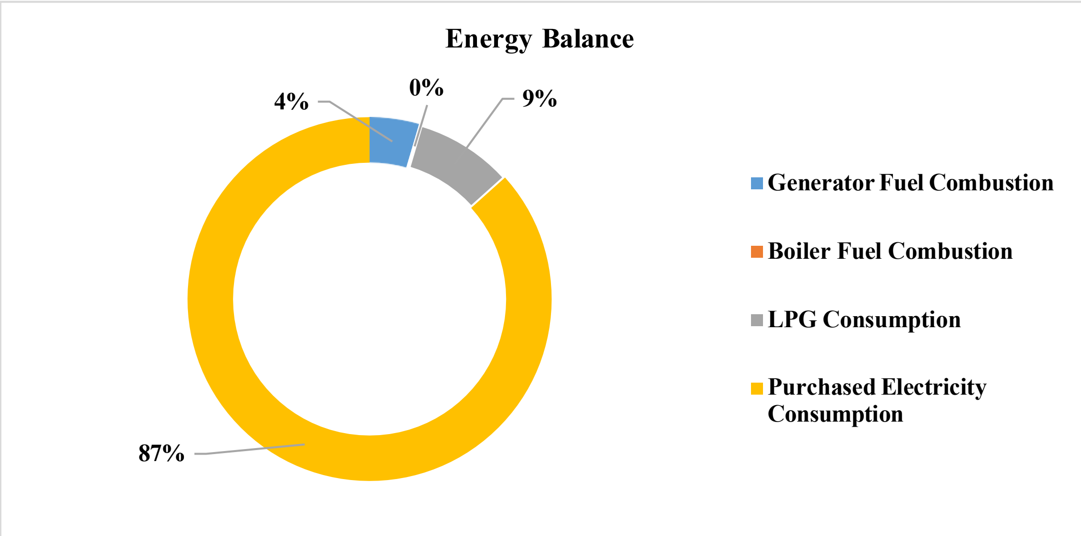

Figure 4-15: Energy balance summary of the case study hotel

Key Performance Indicators

Table 4-9: Key Performance Indicators

	Baseline Hotel KPI		Industry Benchmark
Carbon Emission / Occupied Room	39.33	$kgCO_2e$/Occupied Room	42.00
Electricity Consumption/ Occupied Room	72.29	kWh/ Occupied Room	57.5
Water Consumption/ Occupied Room	3.45	m^3/ Occupied Room	0.49
Waste Generation/ Occupied Room	1.83	kg/ Occupied Room	1.78

When compared with the industry benchmarks, the emissions per occupied room perform slightly better than the average industry performance with the opportunity for further improvement. Energy, Water Performance are considerably lower than the industry average. Anyway, Waste generation per occupied room is slightly low performing yet possible for improvements. Therefore, as key insights of the baseline assessment, the following points can be highlighted.

- The Case study hotel's baseline assessment highlights the significant areas of improvement, particularly in Energy and Water Consumption.
- By focusing on energy efficiency and renewable energy adoption, the hotel can reduce its carbon footprint substantially.
- Water conservation measures also demonstrate high consumption rates highlighting the potential for improvements
- Waste generation is also slightly higher than the industry benchmark. Potential strategies can be explored to achieve reductions

Selection of Retrofits to Evaluate

Referring to the detailed discussion carried out with the technical staff of the hotel, maintenance engineer and sustainability manager, the current sustainability actions were identified. Their insights were used to select the retrofits to evaluate. The selected hotel has already made significant efforts to improve the sustainability means of the hotel through different strategies. In terms of the building and infrastructure, the implementation of switching into more efficient lighting systems, installing submeters for close monitoring of high energy consuming areas, and integration of renewable energy through solar water heater systems are prominent. Since the hotel focuses on improving biodiversity within the premises, they want to consider involving green walls and or roofs as an energy efficiency retrofit which will benefit in a few ways if implemented. Water conservation measures such as low flow faucets, sensor faucets, use of smart irrigation systems, rainwater harvesting etc. minimize the requirement of municipal water creating a huge financial saving. Anyway, there is still room for further improvement. Also, showerheads and toilet improvement are potential options to explore.

Waste Management is also another aspect with ongoing good practices where they segregate the waste properly into separate-colored bins and dispose properly. Food Waste is sent to piggery, Polythene, plastic and paper waste are recycled while waste oil is sent for incineration. Hazardous waste is separately collected and sent for incineration. Anyway, the hotel still uses single-use plastic bottles, the toiletries are also still plastic. The guest registration and other general administration activities are still paper based. Considering above, the retrofits mentioned in Table 4-10 to Table 4-12 were selected for further analysis. There are six energy retrofits, 4 water retrofits and again 6 waste related retrofits to evaluate.

Table 4-10: Energy Retrofit Option

S/N	Energy Retrofit Option
	Lighting System Upgrade
E1.1	Replace inefficient lighting fixtures with LEDs
E1.3	Install motion sensors
	HVAC System Upgrade
E2.1	Convert to inverter AC units
	Building Envelop Improvement
E3.1	Green Roofs and walls
E3.2	Cool Roof involvement
	Renewable Energy Integration
E4.1	Install solar panels

Table 4-11: Water Retrofit Option

S/N	Water Retrofit Option
	Water Fixture Improvement
W1.2	Low flow toilet
W1.3	Low flow showerheads
	Other Water Retrofits
W2.1	Greywater recycling
W2.3	Drip Irrigation System

Table 4-12: Waste Retrofit Option

S/N	Waste Retrofit Option
	Food Waste Management
WS1.2	Waste Management techniques
WS1.3	Composting
	Paper Waste Reduction
WS2.1	Digital Transformation
WS2.3	Inhouse paper recycling center
	Polythene and Plastic Waste Reduction
WS3.1	Onsite water refilling station
WS3.2	Refillable – Eco friendly toiletries

STEP 2: RETROFIT EVALUATION

As per the next step, the selected retrofits were assessed by inserting required information in the "ENERGY, WATER & WASTE RETROFITS" tabs. The evaluation results are summarized in the next tab, "STRATEGIC DECISION FRAMEWORK" Tab in Table 14,15 and 16 as mentioned in Figure 4-16

TABLE 14

	ENERGY RETROFITS	kWh Potential Annual Saving (kWh)	LKR Annual Financial Saving	% emission % from total	kgCO2e Annual Emission saving (kgCO2e)	LKR Initial investment	Maintainance requirement	Payback Period	Technical Complexity	Adaptability
1	**Lighting System Upgrade**									
1.1	Replace inneficient lighting fixtures with LEDs	2,803.20	103,718.40	0.1%	1,199.21	56,400.00	Low	0.54	Low	Low
1.2	Install dimmers	-	-	0.0%	-	-	Low	0	Low	Low
1.3	Install motion sensors	13.14	486.18	0.0%	5.62	8,400.00	Low	17.28	Medium	Medium
1.4	Daylight integration	-	-	0.0%	-	-	Low	0	Medium	Medium
2	**HVAC System Upgrade**									
2.1	Convert to inverter AC units	199,148.66	7,368,500.32	10.0%	85,195.80	24,300,000.00	Medium	3.30	Medium	Medium
2.2	(VSDs)	-	-	0.0%	-	-	Medium	0	Medium	Medium
2.3	Demand Controlled Ventilation	-	-	0.0%	-	-	High	0	High	High
3	**building envelop improvement**									
3.1	green wall and roof	2,964.21	109,675.84	0.1%	1,268.09	836,128.17	High	7.62	High	High
3.2	cool roof	541.49	20,035.21	0.0%	231.65	87,500.00	Low	4.37	Medium	Medium
3.3	blinds and curtains and shading devices	0	-	0.0%	-	-	Low	0	Medium	Medium
3.4	window glass improvement	-	-	0.0%	-	-	Low	0	Low	Low
4	**renewable energy integration**									
4.1	Solar panels	12,984.70	480,433.87	0.7%	5,554.85	1,500,000.00	Medium	3.12	High	High
4.2	Solar Water Heating System	-	-	0.0%	-	-	Medium	0	Medium	Medium
5	**Other**									
5.1	Keycard switches	-	-	0.0%	-	-	Medium	0	Medium	High
5.2	BMS installation (For lights only)	-	-	0.0%	-	-	High	0	High	Medium

Figure 4-16: Table 14 of the excel based framework

TABLE 15

	WATER RETROFITS	m3 Potential Annual Saving (m3)	LKR Annual Financial Saving	kgCO2e emission % from total	kgCO2e Annual Emission saving (kgCO2e)	LKR Initial investment	Maintainance requirement	Payback Period	Technical Complexity	Adaptability
6	**Water Fixture Improvement**									
6.1	Sensor Faucets	-	-	0.0%	-	-	Low	0	Medium	High
6.2	Low Flow Toilets	656.56	98,484.71	0.0%	98.31	860,000.00	Low	8.73	Medium	High
6.3	Low Flow Showerheads	819.01	122,851.44	0.0%	122.63	810,000.00	Low	6.59	Low	High
7	**Other retrofits**									
7.1	Greywater recycling	17,661.36	2,649,204.00	0.3%	2,644.44	2,649,204.00	High	2.08	High	Medium
7.2	Rainwater Harvesting	-	-	0.0%	-	-	Medium	0	Medium	High
7.3	Drip Irrigation System	7,947.61	1,192,141.80	0.1%	1,190.00	22,400.00	Low	0.02	Medium	High

Figure 4-17: Table 15 of the excel based framework

	WASTE RETROFITS	Tonnes Potential Annual Saving	LKR Annual Financial Saving	kgCO2e emission % from total	kgCO2e Annual Emission saving	LKR Initial investment	Maintainance requirement	Payback Period	Technical Complexity	Adaptability
8	**Food Waste Management**									
8.1	Food Waste Reduction	1.87	2,085,255.00	0.0%	-	450,000.00	Low	0.22	Low	High
8.2	Composting	37.32	2,239,200.00	0.0%	(332.60)	100,000.00	Low	0.04	Low	High
8.3	Donation/ Piggery	-	100,000.00	0.0%	-	-	Low	0.00	Low	Medium
9	**Paper Waste Management**									
9.1	Digital transformation	0.82	655,936.00	0.1%	954.71	1,000,000.00	Low	1.52	High	High
9.2	Invest in a paper recycling station	0.92	327,968.00	0.1%	1,051.66	2,400,000.00	High	7.32	High	Medium
9.3	Paper waste Deviate landfill waste to recycle	-	-	0.0%	-	-	Low	0.00	Low	High
10	**Polythene and Plastic Waste Management**									
10.1	Onsite Bottling Plant	0.19	32,334,000.00	0.0%	4.09	3,754,000.00	High	0.12	Low	Medium
10.2	Refillable toilettories	0.67	3,360.00	0.0%	14.30	24,300.00	High	0.00	Low	Medium
10.3	Plastic waste Recycling instead of landfill	-	-	0.0%	-	-	Low	0.00	Low	High

Figure 4-17: Table 16 of the excel based framework

	ENERGY RETROFITS	Emission saving	Initial Investment	Maintainance requirement	Payback Period	Technical Complexity	Adaptability
1	**Lighting System Upgrade**						
1.1	Replace inneficient lighting fixtures with LEDs	Low	Low	Low	Low	Low	Low
1.2	Install dimmers	Low	Low	Low	High	Low	Low
1.3	Install motion sensors	Low	Low	Low	High	Medium	Medium
1.4	Daylight integration	Low	Low	Low	High	Medium	Medium
2	**HVAC System Upgrade**						
2.1	Convert to inverter AC units	High	High	Medium	Medium	Medium	Medium
2.2	(VSDs)	Low	Low	Medium	High	Medium	Medium
2.3	Demand Controlled Ventilation	Low	Low	High	High	High	High
3	**building envelop improvement**						
3.1	green wall and roof	Low	High	High	High	High	High
3.2	cool roof	Low	Low	Low	Medium	Medium	Medium
3.3	blinds and curtains and shading devices	Low	Low	Low	High	Medium	Medium
3.4	window glass improvement	Low	Low	Low	High	Low	Low
4	**renewable energy integration**						
4.1	Solar panels	Low	High	Medium	Medium	High	High
4.2	Solar Water Heating System	Low	Low	Medium	High	Medium	Medium
5	**Other**						
5.1	Keycard switches	Low	Low	Medium	High	Medium	High
5.2	BMS installation (For lights only)	Low	Low	High	High	High	Medium

Figure 4-19: LMH Matrix results (Table 18 - ENERGY) for the case study

As the next step in the decision support model, the LMH Matrix, developed for the normalization for comparison purpose is as shown in Table 18,19 and 20as per Figure 4-19 to Figure 4-21.

Table 19

	WATER RETROFITS	Emission saving	Initial Investment	Maintainance requirement	Payback Period	Technical Complexity	Adaptability
6	Water Fixture Improvement						
6.1	Sensor Faucets	Low	Low	Low	High	Medium	High
6.2	Low Flow Toilets	Low	High	Low	High	Medium	High
6.3	Low Flow Showerheads	Low	High	Low	High	Low	High
7	Other retrofits						
7.1	Greywater recycling	Low	High	High	Medium	High	Medium
7.2	Rainwater Harvesting	Low	Low	Medium	High	Medium	High
7.3	Drip Irrigation System	Low	Low	Low	Low	Medium	High

Figure 4-20:LMH. Matrix results (Table 19 - WATER) for the case study

Table 20

	WASTE RETROFITS	Emission saving	Initial Investment	Maintainance requirement	Payback Period	Technical Complexity	Adaptability
8	Food Waste Management						
8.1	Food Waste Reduction	Low	Medium	Low	Low	Low	High
8.2	Composting	Low	Medium	Low	Low	Low	High
8.3	Donation/ Piggery	Low	Low	Low	Low	Low	Medium
9	Paper Waste Management						
9.1	Digital transformation	Low	High	Low	Low	High	High
9.2	Invest in a paper recycling station	Low	High	High	High	High	Medium
9.3	Paper waste Deviate landfill waste to recycle	Low	Low	Low	Low	Low	High
10	Polythene and Plastic Waste Management						
10	Onsite Bottling Plant	Low	High	High	Low	Low	Medium
10	Refillable toilettories	Low	Low	High	Low	Low	Medium
10	Plastic waste Recycling instead of landfill	Low	Low	Low	Low	Low	High

Figure 4-21:LMH Matrix results (Table 20 - WASTE) for the case study

After scoring LMH according to Table 21-23 and multiplying each with the pre-determined priority vectors, the final weighted decision matrix is developed, and the total score is utilized for the ranking purpose as per Figure 4-22 to Figure 4-24.

	ENERGY RETROFITS	Emission saving	Initial Investment	Maintainance requirement	Payback Period	Technical Complexity	Adaptability	Total Score	Rank
		Table 21							
		0.38	0.17	0.10	0.06	0.05	0.24		
1	Lighting System Upgrade								
1.1	Replace innefficient lighting fixtures with LEDs	0.38	0.51	0.31	0.19	0.14	0.24	1.76	4
1.2	Install dimmers	0.00	0.00	0.00	0.00	0.00	0.00	0.00	NA
1.3	Install motion sensors	0.38	0.51	0.31	0.06	0.09	0.47	1.83	3
1.4	Daylight integration	0.00	0.00	0.00	0.00	0.00	0.00	0.00	NA
2	HVAC System Upgrade								
2.1	Convert to inverter AC units	1.14	0.17	0.20	0.13	0.09	0.47	2.21	1
2.2	(VSDs)	0.00	0.00	0.00	0.00	0.00	0.00	0.00	NA
2.3	Demand Controlled Ventilation	0.00	0.00	0.00	0.00	0.00	0.00	0.00	NA
3	building envelop improvement								
3.1	green wall and roof	0.38	0.17	0.10	0.06	0.05	0.71	1.47	6
3.2	cool roof	0.38	0.51	0.31	0.13	0.09	0.47	1.89	2
3.3	blinds and curtains and shading devices	0.00	0.00	0.00	0.00	0.00	0.00	0.00	NA
3.4	window glass improvement	0.00	0.00	0.00	0.00	0.00	0.00	0.00	NA
4	renewable energy integration								
4.1	Solar panels	0.38	0.17	0.20	0.13	0.05	0.71	1.64	5
4.2	Solar Water Heating System	0.00	0.00	0.00	0.00	0.00	0.00	0.00	NA
5	Other								
5.1	Keycard switches	0.00	0.00	0.00	0.00	0.00	0.00	0.00	NA
5.2	BMS installation (For lights only)	0.00	0.00	0.00	0.00	0.00	0.00	0.00	NA

Figure 4-22: Weighted Decision Matrix (Table 21 - ENERGY)

		saving	Investment	requirement	Period	Complexity			
6	Water Fixture Improvement								
6.1	Sensor Faucets	0.00	0.00	0.00	0.00	0.00	0.00	0.00	NA
6.2	Low Flow Toilets	0.38	0.17	0.31	0.06	0.09	0.47	1.49	3
6.3	Low Flow Showerheads	0.38	0.17	0.31	0.06	0.14	0.24	1.29	4
7	Other retrofits								
7.1	Greywater recycling	0.38	0.17	0.10	0.13	0.05	0.71	1.54	2
7.2	Rainwater Harvesting	0.00	0.00	0.00	0.00	0.00	0.00	0.00	NA
7.3	Drip Irrigation System	0.38	0.51	0.31	0.19	0.09	0.47	1.95	1

Figure 4-23: Weighted Decision Matrix (Table 22 - WATER)

	WASTE RETROFITS	Emission saving	Initial Investment	Maintainance requirement	Payback Period	Technical Complexity	Adaptability	Total Score	Rank
		Table 23							
		0.38	0.17	0.10	0.06	0.05	0.24		
8	Food Waste Management								
8.1	Food Waste Reduction	0.00	0.34	0.31	0.19	0.14	0.24	1.21	6
8.2	Composting	0.38	0.34	0.31	0.19	0.14	0.24	1.59	2
8.3	Donation/ Piggery	0.00	0.00	0.00	0.00	0.00	0.00	0.00	NA
9	Paper Waste Management								
9.1	Digital transformation	0.38	0.17	0.31	0.19	0.05	0.71	1.80	1
9.2	Invest in a paper recycling station	0.38	0.17	0.10	0.06	0.05	0.71	1.47	4
9.3	Paper waste Deviate landfill waste to recycle	0.00	0.00	0.00	0.00	0.00	0.00	0.00	NA
10	Polythene and Plastic Waste Management								
10.1	Onsite Bottling Plant	0.38	0.17	0.10	0.19	0.14	0.24	1.22	5
10.2	Refillable toilettories	0.38	0.51	0.10	0.19	0.14	0.24	1.56	3
10.3	Plastic waste Recycling instead of landfill	0.00	0.00	0.00	0.00	0.00	0.00	0.00	NA

Figure 4-24: Weighted Decision Matrix (Table 23 - WASTE)

Finally, after all these steps, the ranked retrofit options are displayed in Table

10, 11 and 12 separately for Energy, Water and Waste Sections and combined ranking of the retrofits considered are displayed in Table 13 in the Excel Tool (Figure 4-25). For this particular case study hotel considered 16 retrofits and finally, the considering all the decision-making factors; Annual Emissions Saving, Initial Investment, Maintenance Requirement, Payback Period, Technical complexity and Adaptability, the options are ranked as follows.

Table 13

FINAL RESULTS - COMBINED

Rank	Strategy
1	**Convert to inverter AC units**
2	**Drip irrigation System**
3	**cool roof**
4	Install motion sensors
5	Digital transformation
6	Replace inneficient lighting fixtures with LEDs
7	Solar panels
8	Composting
9	Refillable toilettories
10	Greywater recycling
11	Low Flow Toilets
12	green wall and roof
12	Invest in a paper recycling station
14	Low Flow Showerheads
15	Onsite Bottling Plant
16	Food Waste Reduction

Figure 4-25: Final Ranking List of Selected Retrofits – Combined (Table 13 in Excel Based Framework)

Energy Retrofit Analysis Insights

The developed decision support model utilized in this study provides a comprehensive framework to evaluate and prioritize sustainable retrofits for the hotel. If energy retrofits are considered separately, several key insights as per Table 10 in "ANALYSIS & RESULTS" tab (Figure 4-26) highlight the utility and effectiveness of this framework in guiding sustainable retrofitting decisions.

Conversion of conventional air conditioners to inverter type ones emerges as the most feasible solution for this particular hotel among the selected retrofits. It scores highest primarily due to its significant emission saving potential being the highest among all considered options. The high adaptability, minimal operational disruptions, moderate initial investment, and relatively low payback period has made this option more attractive. This elaborates the importance of balancing both environmental and financial concerns in retrofit related decision making.

Table 10

FINAL RESULTS - ENERGY	
Rank	**Strategy**
1	**Convert to inverter AC units**
2	**cool roof**
3	**Install motion sensors**
4	Replace ineficient lighting fixtures with LEDs
5	Solar panels
6	green wall and roof
NA	Install dimmers
NA	Daylight integration
NA	Variable Speed Drives - Chilled and Condenser Water pumps (VSDs)
NA	Demand Controlled Ventilation
NA	blinds and curtains and shading devices
NA	window glass improvement
NA	Solar Water Heating System
NA	Keycard switches
NA	BMS installation (For lights only)

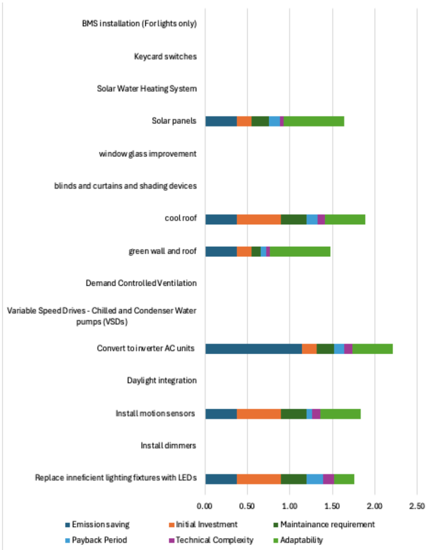

Figure 4-26: Final Ranking List of Selected Energy Retrofits (Table 10)

Cool roof installation has been the second preferred retrofitting option due to its lower initial investments compared to other high impact options such as green roofs. Cool roofs give higher energy saving potential with moderate maintenance requirements and technical complexity contributing to a higher ranking. Therefore, this solution also indicates a balanced cost, impact and complexity being a desirable sustainable retrofit. As the third preference installing motion sensors is favored due its low initial investment and quick payback period. Even if it has comparatively lower emission saving potential than conversion of ACs, the overall effectiveness and minimal technical complexity and higher adaptability make it an attractive option. This highlights the fact that the potential for smaller less costly interventions can still make meaningful impacts on energy efficiency.

Despite the higher emission saving potential, solar panels are less preferred in this particular hotel as a sustainable retrofit due to the high initial investment and technical complexity. The limited roof space has further reduced the feasibility of this option since it constrains solar energy generation potential. This highlights the need to consider physical constraints and long-term financial commitments when evaluating renewable energy options. Retrofitting the lighting system by converting to LEDs and installing motion sensors scores higher due to low upfront cost and significant long-term energy saving potential. Even if the emission savings are moderate, the cost effectiveness and lower technical complexity and reduced maintenance cost are feasible. Likewise, this demonstrates the importance and balancing immediate costs with long term benefits.

When looked at the cool roof and green roof options, the cool roof is preferred due to lower initial investment over the similar energy saving potential. Higher maintenance cost and further diminishes the preference with green roof option. This comparison illustrates the capability of the developed model to discern between seemingly similar options considering a wider range of factors.

Water Retrofit Analysis Insights

Table 11

FINAL RESULTS - WATER	
Rank	**Strategy**
1	**Drip Irrigation System**
2	**Greywater recycling**
3	**Low Flow Toilets**
4	Low Flow Showerheads
NA	Sensor Faucets
NA	Rainwater Harvesting

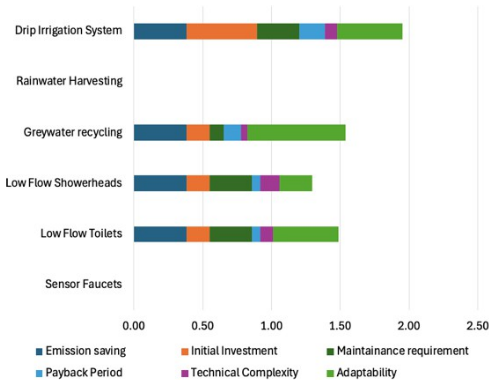

Figure 4-27:Final ranking list of water retrofits (Table 11)

As per the results of comparing water retrofits separately, rankings of the selected 4 strategies are mentioned in Table 11 in “ANALYSIS & RESULTS” tab and as per Figure 4-27. In the separate water retrofit analysis, it highlights that the drip irrigation system as a more feasible water retrofit option for this hotel. The reasons behind this selection are primarily due to its significant potential for water conservation and emissions saving. moderate initial investment and low maintenance requirement may have caused the ranking. Moderate payback period, low technical complexity and higher adaptability have strengthened the top ranking of this option. Therefore, combination of all these factors have made this retrofit option as the highly desirable option for sustainable water management in this particular hotel. Greywater recycling has obtained the second place of the ranking with similar energy saving potential but less preference on initial investment since it is a high investment strategy. Apart from that both technical complexity and maintenance requirement are higher than drip irrigation system. But, since their huge generation of greywater within a day which may require only a small effort to treat and use for non-potable water requirement, the adaptability is higher and indirectly this may be able to couple with other strategies like drip irrigation system, improving water efficiency as well as reduced potable water requirement which results in huge financial saving. Transforming into low flow toilets and low flow showerheads are another effective way of reducing water usage and emissions. Due to their low initial investment, lower maintenance, and quick payback periods. The cost effectiveness and ease of implementation has made this option an attractive one for water sustainability. The value of small-scale options that are low cost in achieving significant water conservation goals is well highlighted through this.

Waste Retrofit Analysis Insights

As per the results of comparing waste retrofits separately, rankings of the selected 6 strategies are mentioned in Table 12 (Figure 4-28) in "ANALYSIS & RESULTS" tab.

Table 12

FINAL RESULTS - WASTE

Rank	Strategy
1	**Digital transformation**
2	**Composting**
3	**Refillable toilettories**
4	Invest in a paper recycling station
5	Onsite Bottling Plant
6	Food Waste Reduction
NA	Donation/ Piggery
NA	Paper waste Deviate landfill waste to recycle
NA	Plastic waste Recycling instead of landfill

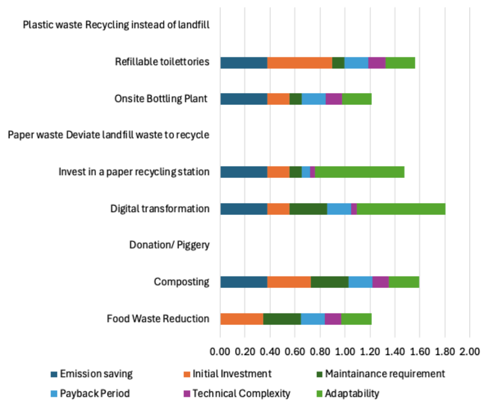

Figure 4-28: Final Ranking List of Waste Retrofits (Table 12)

Digital transformation has obtained the first rank out of the six. The major reasons behind the selection are the higher adaptability to the existing system and low maintenance requirements. Even if the initial investment is lower than rest of the strategies, it pays off soon compared to other options. Composting is also another preferable option for food waste in the hotel. Apart from the reduced GHG Emissions, Lower initial investment and lower maintenance requirements make it a more attractive option. Eco friendly toiletries (Refillable) are the most cost-effective strategy with almost the same preference for emission reduction while reducing huge amounts of plastic as waste. A high preference for technical complexity with a moderate preference for adaptability has strengthened the preference for this option. Food waste management strategies are also a cost-effective strategy even if it does not indicate any emission reduction, since the food is disposed as piggery (Reused) in this particular hotel. Inventory management, Menu planning, Buffet management, Portion Control, Food waste Tracking are the simple management techniques that were considered. Due to the huge variability of each strategy, all these were considered as a combined strategy. This will not only reduce waste generation, but also will result in huge financial savings simply just adjusting the operational practices. Paper recycling centers are also a great strategy to reduce emissions by deviating waste from landfills. Paper waste, being a major component of the total waste generated in a hotel, this initiative will support reducing emissions with a huge financial savings. Not only that it will enhance the brand loyalty of the hotel.

Combined Results Analysis Insights

When the retrofit options are ranked as a combination, the top 5 ranks have been given for; Convert to inverter AC units, Drip Irrigation System, Cool Roof, Install motion sensors and Digital transformation. Apart from the AC conversion option and Digital transformation option, all other top 3 options are low Initial Investment options resulting almost similar emission reduction potential. All top strategies are highly adaptable and considerably low – Medium Technical complexity and low maintenance requirement.

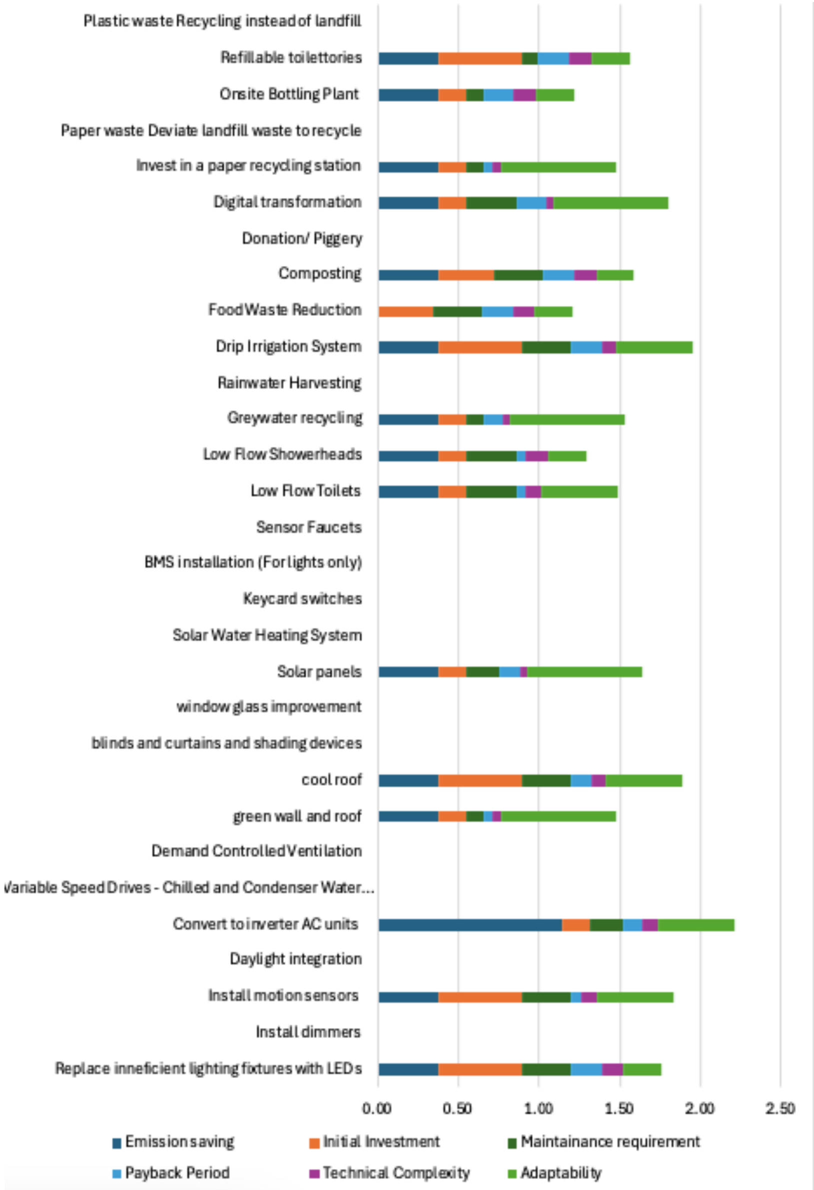

Figure 4-18: Retrofit Analysis Summary

4.5. Recommendations and Best Practices

This section provides improved recommendations and best practices for using the developed framework effectively in sustainable retrofit projects in tourist and resort type hotels in Sri Lanka. This framework aims to guide the decision makers in selecting and implementing the strategies that are most impactful in terms of reducing GHG Emissions while balancing financial and technical perspectives as well. The following recommendations are structures to support different stages or aspects of the retrofitting process from initial evaluation to implementation and maintenance.

Prioritize High Impact, Low-Cost Retrofits

It is recommended to begin with retrofit strategies that offer substantial benefits with low initial investment and technical complexity. Related to the case study conducted, the examples can be given as Cool Roofs, motion sensors or Conversion to LEDs. These options will provide immediate improvements and emission reductions. In this process it is important to use existing infrastructure and resources to minimize costs and disruption. It is highly recommended to identify the section wise energy, water and waste generation. This can be assessed through sub meters for water and electricity, proper monitoring and recording of the waste quantities generated in each section. It will help developing the implementation plan identifying areas to prioritize. It is crucial to involve the key stakeholders including hotel management and staff in the implementation process planning. Their support will be helpful to avoid potential reductions in guest experience in the implementation stage.

Evaluate Space and Operational Constraints

It is important to consider the available roof and ground space to maximize the benefits specially when space intensive retrofits such as rainwater harvesting and solar panel projects are considered. For an example, if an implementation of a certain retrofit strategy is involved with significant downtime or disrupts guest experience should be carefully planned to avoid or minimize inconvenience. This can be resolved if the implementation is planned in few phases. This phase wise implementation will be helpful in managing costs and minimizing disruption. Also, it will allow for gradual improvements and provide the opportunity to assess the impact of each phase before implementing the rest.

Comprehensive Maintenance Planning

It is important to ensure all retrofits include comprehensive maintenance plans to sustain performance and efficiency over time. It may include regular inspections, preventive maintenance actions and prompt repairs when needed. Also, it is essential to provide necessary training for hotel staff on the operation and maintenance of new systems and installed technologies. It will ensure the retrofits are properly managed. This strategy can be strengthened through establishing maintenance schedules for each retrofit, detailing the frequency and scope of maintenance activities. It will help prevent issues ensuring long-term reliability. Parallel to this, a monitoring system can be implemented to track the performance of each retrofit.

Consider Long Term Benefits

Apart from initial investment and payback period, long term financial benefits can be considered when making the final decision on selecting and implementing retrofits. Reduced utility bills, maintenance costs will be highly beneficial as same as reduced initial cost. This can systematically do through a life cycle cost analysis. It is important to highlight all these sustainability efforts to guests and stakeholders to enhance the hotel's reputation attracting eco conscious travelers. Obtaining sustainability certifications such as LEED, Green Key will validate and promote hotel's commitment to sustainability. Additionally, those will provide a framework for continuous improvement. The developed framework for sustainable retrofitting in small to medium tourist and resort type hotels is an important tool for driving meaningful environmental and economic improvements. The systematic approach starting from identifying the current performance status of the hotel in Energy, Water and Waste, assesses and ranks relevant retrofitting options, allowing hotels to make data-driven decisions prioritizing low-cost high impact strategies.

The holistic approach of the framework integrates six criteria; Annual emissions saving potential, Adaptability, Initial Investment, Payback period, Technical Complexity and Maintenance Requirement, ensure each retrofit is evaluated comprehensively. Apart from identifying most feasible option, it aligns with the hotel's operational and financial capabilities of the hotel. The inclusion of water and waste additionally to energy, further underscores the framework's versatility and its capacity to address multiple aspects of sustainability. The framework ensures the sustained performance by providing a clear roadmap for implementation and provide guidelines for monitoring, maintenance and continuous improvement. Finally, the developed framework can be introduced as a vital instrument for small to medium hotels aiming to enhance their sustainability performance. This framework not only for individual hotels, but also contributes to the wider efforts of mitigating climate change while promoting sustainable tourism practices in Sri Lanka.

CHAPTER 5

5. Conclusion

This is a comprehensive synthesis of the study conducted on sustainable retrofitting strategies for small to medium resort type hotels in Sri Lanka to achieve decarbonization goals. This research aimed to develop an actional and practical guideline for enhancing sustainability in such hotels ensuring operational efficiency, mainly energy, water and resource consumption performance. Through this chapter, the key findings, their implications for the industry, limitations of the study and suggestions for future research will be stated.

5.1. Summary of Key Findings

The research identified the baseline performance of small to medium resort type Sri Lankan hotels through the sample analysis. The results of the study clearly depict the importance of enhancing energy performance of hotels since over 80% of the GHG emissions in such hotels are contributed from energy. It was revealed that, even if water and waste do not much contribute to GHG Emissions, the impact on cost is significant. Key performance Indicators such as Energy consumption per occupied room, water usage, waste generation and GHG emission per occupied room were used to measure the performance. Improving the energy, water and waste performance of hotels were identified as crucial activities for reducing cost and minimizing GHG Emissions. Thereby it supports enhancing overall sustainability profile of the hotel attracting eco-conscious guests.

Another key finding is that the decision-making concerns of hotel stakeholders when implementing a new strategy in operation. Setting the major objective as reducing GHG Emissions, the following decision-making concerns were identified as the decision criteria for the analysis which was conducted through Analytical Hierarchy Process (AHP). Accordingly, Annual Emissions Saving, Adaptability, Initial Investment, Payback Period, Maintenance Requirement and Technical Complexity were selected as the decision criteria. Further, this research focused on identifying widely used retrofitting techniques under the water, energy and waste performance. The identified 30 retrofits which are feasible and effective for small to medium hotels, were assessed separately through mixed method approach, both quantitative and qualitative.

5.2. Implications for the Hospitality Industry

The findings of this research have important implications for the hospitality industry, especially for small to medium size hotels that operate with limited resources. The developed guideline and framework enable them to systematically evaluate their current emissions through the GHG Emissions Calculator and to make informed decisions on strategies to implement to reduce emissions through the framework developed. Since the framework allows comparing current performance with local Benchmarks which were developed based on the sample analysis, the challenge of supporting hoteliers to make informed decisions on implementing sustainable retrofits is resolved.

5.3. Limitations of the study

Even if the study offers a wide range of insights, it is essential to acknowledge the limitations. Scope wises this research focused on small to medium hotels. Therefore, it will not be directly applicable to larger hotels. The case studies are based on Sri Lanka which may limit the generalization of the results. The study timeframe was limited, and long-term impacts of sustainable retrofits were not fully explored. However, few longitudinal studies can be implemented to assess the sustainable benefits and potential changes over time. Also, the retrofitting strategies selected for this study were only the widely used ones. However, there are many strategies that are involved with the latest technology and those have not been assessed in this framework.

5.4. Recommendations for Future Research

Future research should address the limitations identified and expand the scope of the study to provide a more comprehensive understanding of sustainable retrofitting in the hotel industry. Accordingly, the study can be expanded to a broader range of hotel sizes and types including larger resorts and city hotels to understand how different scales and operational complexities affect retrofitting strategies. Additionally, expanding to other geographic regions will enable identifying region-specific solutions accounting for local climate conditions, regulatory frameworks and market dynamics. Another important area for future research is the impact of behavioral changes on hotel operations. Investigating how guests and staff engage with sustainable practices can provide deeper insights into the human factors that influence the effectiveness of retrofitting measures. By considering behavioral patterns and preferences, hotels can develop more targeted and effective strategies for promoting sustainability. Collectively, these expanded research efforts will offer a holistic view of sustainable retrofitting guiding the industry towards more resilient and environmentally friendly practices.

CHAPTER 6

6. References

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