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Net-Zero Pathways for Thailand's Hotel Sector: Strategic Roadmaps and Technological Adoption (2030-2040)

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***Abstract* – The Thai hotel industry is an essential sector in Thailand's economy, but it also has an impact on greenhouse gas emissions due to high energy consumption in construction processes like air conditioning, lighting, heating, and waste disposal. This study aims to investigate the ways and strategies that can be taken towards achieving net-zero emissions in Thailand's hotel industry between 2030 and 2040, focusing on major tourist destinations like Bangkok, Phuket, and Chiang Mai. A heat model has been applied in this study to analyze emissions during the maintenance phase in the construction of hotel buildings. It has been found that there are differences in emissions in these regions due to dissimilarities in climate and structural conditions. Bangkok has lower emissions compared to Phuket and Chiang Mai. Technologies that can be applied in achieving net-zero emissions have also been identified in this study, including solar photovoltaic, solar thermal, heat pump, wind power, waste heat, and energy efficiency in building construction and operation. Strategic roadmaps have been proposed in achieving these technologies in the short term (2023-2025), medium term (2026-2030), and long term (2031-2040). These have been aligned with Thailand's Sustainable Tourism Goals (STGs). Moreover, the study has emphasized the significance of monitoring and evaluation mechanisms through key performance indicators like energy consumption, renewable energy, and waste. Despite these opportunities, there are challenges in achieving net-zero emissions, including financial, technological, and regulatory issues, particularly in small and medium-sized hotel enterprises. It has been concluded in this study that, with the application of renewable energy technologies and energy efficiency, Thailand can move towards achieving sustainability in its hotel industry.**

***Keywords*- Net-zero emissions; Sustainable tourism; Hotel sector decarbonization; Renewable energy; Solar photovoltaic; Energy efficiency; Thailand tourism industry; Sustainable Tourism Goals (STGs); Carbon emission reduction; Green hotel technologies.**

I. INTRODUCTION

The hotel industry is crucial to the Thai economy and to providing employment opportunities within the country. The fundamental aspect to be considered for the future of the country is that these structures should be made to achieve net-zero emissions by 2030–2040. In this work, a heat model is presented for a hotel to calculate emissions during the maintenance phase. Three cities in Thailand are considered: Phuket, Chiang Mai, and Bangkok. Various technologies are presented for hotel structures to achieve net- zero emissions by 2030. Analysis of the heat model shows that the hotel structure in Bangkok has lower emissions due to differences in mixtures of climate between these two cities. For achieving net-zero emissions, various roadmaps are presented. The Phuket hotel structure is considered to present a reference for achieving net-zero emissions by 2030–2040. For achieving this target, various technologies should be adopted, and this is only possible through ad-hoc policies to achieve this target. Emissions during the operational phase of hotel structures include hardware appliances such as light, sockets, lifts, air conditioning systems, and water heaters. The design of the building, i.e., covering, as well as the climate area, impacts emissions related to changes in air-conditioning needs and solar heat gain. The best solution for air-conditioning needs and water heating needs for the hotel sector in Thailand is a combination of solar photovoltaic and solar thermal power plants. The need for hot water is significant during most of the time of the year; thus, solar thermal power plant coupled with an air to water heat pump is the major solution. Energy efficiency is fundamental to reducing emissions for a hotel that operates within this region. The number of solar panels, solar photovoltaic groups, as well as seamless energy storage tanks for different sectors of energy, are essential determinants of emissions for a structure that is moving forward to net-zero emissions (Nocera et al., 2019). The framework for incorporating this into the national Sustainable Tourism Goals (STGs) is defined to ensure that objectives are met by moving forward within this framework (Pita et al., 2020). This phase is related to scheduled data collection and storage to ensure that it is possible to regularly measure Key Performance Indicators (KPIs) related to the STGs.

II. BACKGROUND

The population of Thailand in 2020 was 69.43 million people, with the urban population making up 51%. Tourism receipts in 2019 reached approximately 3.5 trillion baht. The sectors of residential buildings, commercial buildings, construction, and tourism accounted for 27% of the total GDP in 2019. Tourism sector revenues, including accommodations, reached 595 billion baht in 2019. On average, the tourism sector grew at an

annual rate of 22.3% between 1996 and 2017. Hotels are using technology to reduce emissions in line with the Sustainable Tourism (ST) Goals' key performance indicators (KPIs) as Thailand targets net-zero emissions between 2030 and 2040 (Pita et al., 2020). The above provides an overview of the hotel industry in Thailand in terms of its structure and contribution to energy-related carbon dioxide (CO2) emissions.

Overview of Thailand's Hotel Sector

A significant sector of Thailand's tourism industry is hotel operations. Therefore, the government's low- carbon development strategy will be heavily influenced by the decarbonization of the hotel sector. The government's newly proposed Sustainable Tourism Goals (STGs) will be an important way of maintaining the climate action in the invitation-to-action period of 2030–2040. The quantification of the emissions of the hotel sector in the year 2030 will be done using the number of emissions (gigagrams carbon-dioxide equivalent, $GgCO_2e$), temperature-weighted quantification, and parts of the present national climate plans. The reduction potential of the pertinent technology, which will be solar photovoltaic, wind power, and energy and water efficiency, will be emphasized. The quantification will be important in creating mid- and long-term roadmaps for the transition of the hotel sector to low carbon in which the hotels will be using different technology mixes to achieve the STGs while considering the presently emphasized areas of the STGs in Bangkok, Phuket, and Chiang Mai. The roadmaps will be supported by an implementation framework that will define the roles of the government, the firms, and the finance.

The hotel industry in Thailand includes a variety of hotel types, from motels and bed-and-breakfast hotels on one end of the scale, through to luxury tourism and resort hotels on the other end of the scale, and all of the associated travel and hospitality industries. The hotel industry is a significant part of Thailand's tourism industry, which accounts for 20% of Thailand's gross national product, with 18% of Thailand's population being employed in the industry (Ba et al., 2022). Efforts are needed to decarbonize the hotel industry, and it is a significant step towards the government's low-carbon development goals. The newly announced Sustainable Tourism Goal policy framework is a significant opportunity for a hook upon which to hang a variety of mitigation activities that are focused on the 2030–2040 timescale.

The national climate pledge, also known as the Nationally Determined Contribution (NDC) under the Paris Agreement, targets a reduction in greenhouse gas emissions by 20-25% in 2020-2030, compared to a "business-as-usual" scenario. However, a higher ambition in line with the 1.5 °C goal is required, in line with the "Invitation to Action" by 2030, as recommended by the United Nations Framework Convention on Climate Change (UNFCCC) to achieve alignment with the 2050 net-zero goal. A zero carbon society transition is a broad range of interrelated technology options, also referred to as configuration routes. When considering the hotel industry in Thailand, for example, the following questions arise: Which configuration, i.e., a specific mix of technological resources, is most appropriate for a specific sector? What conditions shape the emergence of a specific transition pattern? Data from Phuket, Chiang Mai, and Bangkok, the best tourist destinations in Thailand, is available.

Importance of Net-Zero Emissions

Considering that the hospitality industry contributes more than 5.5% to Thailand's gross domestic product and 11% to its total workforce, the government has placed emphasis on the significance of strategic development roadmaps to be used in the transition to net-zero emissions. The proposed roadmaps are underpinned by quantitative models, scenario analysis, and a strong methodology to address some of the major challenges associated with the transition to net-zero emissions arising from changes in global standards, suppliers, markets, tourists, and environmental conditions. Net-zero-related technologies are identified as major enablers considering the multi-dimensional role of the hospitality industry in socio-economic development and high energy and resource usage. The first systematic framework for a region- wide transition is proposed to be implemented between 2021 and 2050. Other frameworks are proposed to be implemented between 2021 and 2030 and between 2031 and 2040 to ensure sustainable business and production planning in the medium to long term. Net-zero-related technologies are analyzed through a quantitative model projecting the emissions requirements and costs for four hotel groups in Phuket. Based on greenhouse emissions as a sustainability indicator, major steps are proposed for the adoption of net-zero-related technologies between 2021 and 2030 and between 2031 and 2040. These are then integrated with an overall framework for transition. These are aligned with Thailand's key Sustainable Tourism Goals (STG), which include clear indicators and key performance indicators (KPIs) to be implemented at national and hotel levels to ensure effective management (Masoud Sajjadian, 2023) (Chan and Sopian, 2022).

Sustainable Tourism Goals (STGs)

Sustainable tourism goals (STGs) provide support in moving from traditional measures, like GDP, towards wellbeing and sustainability, defined in terms of reduced carbon emissions. The expected increase in Thailand's tourism industry contradicts the need to decrease emissions, thus underlining the current dilemma in pursuing tourism revenues and emissions, as was highlighted in Sun et al. (2020). Quantitative modelling has shown that there is a need for the hotel industry to meet STG target benchmarks in reducing emissions, in accordance with national target benchmarks that need to be

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met in 2030. A strategic approach in achieving these target benchmarks, in accordance with STGs, has been shown in Ternel (2017) in terms of technology adoption and the development of strategic roadmaps.

III. CURRENT EMISSIONS LANDSCAPE

The hotel industry is a crucial sector of the Thai economy. However, the hotel sector is a key contributor to the emission of greenhouse gases (GHGs) in Thailand. Quantitative emissions analysis and modelling are crucial in identifying the key GHG emission sources, channels, and opportunities for mitigating technology. To mitigate climate change and reduce the rise in temperature levels, net zero emissions are required to achieve the Sustainable Tourism Goals (STGs). Thailand is home to 150,000 hotel establishments. It is one of the most popular tourist destinations globally. In 2019, Thailand recorded 39.8 million tourists. The key emission sources include electricity consumption, air conditioning, food, water, and waste. However, the composition of hotels in the regions and the intensity of emissions are heterogeneous. Understanding the diversity of the hotel sector is a prerequisite for signposting technological opportunities and the hotel sector's decarbonisation. The regions selected for the study are the provinces of Phuket, Chiang Mai, and Bangkok. These regions are selected because the first two are popular destinations for tourist hotels. However, the composition of hotels in Bangkok is diverse.
The hotels in Phuket show a high level of CO2 footprint with high standards of services, large sizes, and high demand for conducting business conferences. The hotels in Chiang Mai show a relatively high level of energy intensity, with many small hotels and a low level of computerization, thus showing a high footprint in proportion to the total guest nights. The hotels in Bangkok show a relatively low increase in GHG emissions, considering the high degree of diversification and maturity in the hotel industry and the success in efficiency improvements in recent years. A specific procedure for the identification of the exact GHG emissions and the respective intensities for the three archetype provinces is a significant step for a quantitative typological characterization of the hotels sector's emissions profile, a crucial interlocking component for the identification of the best technologies and strategies for a phase-out schedule. (Pita et al., 2020) (Ma et al., 2021)

Emission Sources in Hotels

The emissions from Thailand's hotels are site-specific. Electricity consumption, water supply, waste treatment, and refrigeration cooling are the major sources of emissions. Propane tanks are also very popular in hotels. Hence, they are one of the major sources of emissions.
The major source of emissions from hotel buildings is due to excessive use of electricity. This is because hotels are open for longer hours. Hence, there is excessive use of electricity for lighting and cooling purposes. The second major source of emissions from hotels is due to excessive use of water and waste treatment. This is because hotels use Asia's electricity mix to completely clean water and wastewater. It is discouraging that the emissions from sewage treatment are equal in value to those from lighting, cooling, and water supply. Propane tanks are the least major source of emissions.

Regional Emission Profiles: Phuket, Chiang Mai, Bangkok

In the year 2016, Thailand's hotel industry absorbed approximately 33,431 TJ of total energy and emitted 2,015 ktCO2-e of greenhouse gases, considering both direct and indirect sources. At the same time, it released 5.94 ktPM, 102.48 ktNOx, and 64.97 ktSO2 into the air. However, with the Sustainable Tourism Goals scenario, it is expected that by the year 2030, the hotel industry will reduce its emissions by a huge margin and will emit approximately 1,000 ktCO2-e, 3.5 ktPM, 55 ktNOx, and 35 ktSO2 into the air. A closer look at the hotel industry's operations reveals that there are significant regional differences, especially regarding Phuket, Chiang Mai, and Bangkok, which demands location-specific strategies for the hotel industry (Pita et al., 2020).

The hotel industry in Phuket operates for long hours, consumes a lot of electricity, and lacks the use of clean sources of energy. Unlike the hotel industries of many global destinations, Phuket lacks solar, geothermal, and wind energy usage. The hotel industry of Phuket depends largely on electricity, and during peak seasons, the electricity supplied by the grid is produced by coal and gas plants. The use of carbon-intensive fuels for electricity production is the major cause of indirect emissions from the hotel industry of Phuket.

In Chiang Mai, the hotel industry's central air conditioning and central water heating systems cause a significant amount of fuel usage during peak seasons of check-in and check-out. The electricity supplied to the hotel industry of Chiang Mai has a high carbon emission rate, especially due to the use of biomass for electricity production, as compared to Bangkok and Phuket. Bangkok is the biggest market for hotel industries, as it is home to almost half of Thailand's hotel and resort industries, with over 80% of the hotel industries operating throughout the year, thus requiring a huge amount of fuels, as indicated by Tangthieng (2017). It is projected that the hotel industry as a whole will need a reduction of approximately 8–15% in GHG emissions annually to achieve the STG.

IV. TECHNOLOGICAL SOLUTIONS FOR EMISSION REDUCTION

Technology options for cutting carbon emissions and moving towards a net zero future include solar photovoltaics, wind power, heat pumps, and waste heat recovery technologies. The existing emission patterns of

Thai hotels, as outlined above, will determine which of the technologies are best for the hotel industry.

The solar photovoltaic technology is useful for cutting carbon emissions by providing alternative and supplementary energy that is renewable and clean. In the case of Thailand's coastal region, wind power is better than solar power, given that it has a greater number of hours operating at full capacity. In addition, wind power is cheaper than solar power, though there may be a problem of space and constraints for onshore sites.

The heat pump technology is useful for cutting carbon emissions by providing a fossil-fuel-free alternative for providing heat, given that it works by compressing air and utilizing a heat exchanger for greater efficiency. High-grade heat pumps that operate with a vacuum and absorption cycle are useful for cutting carbon emissions by providing a fossil-fuel-free alternative for providing heat up to 150°C. The waste heat recovery technology is useful for cutting carbon emissions by providing alternative and supplementary energy from heat sources such as exhaust boilers, chillers, washing machines, and dishwashers. Although combined heat and power technologies are useful for providing alternative and supplementary energy, the small heating demands of hotel buildings make it less viable compared to waste heat recovery technologies.

Solar Energy Adoption

Solar PV is at the heart of reducing emissions related to hotels in Thailand, as existing rooftop solar potential within the sector exceeds demand several times over. Ongoing policy support is necessary. Being a developing country, Thailand is actively promoting solar as a means of reducing greenhouse emissions and air pollutants. The country is aiming to use 30% of its total energy from renewables by 2036, which includes 6,000 MW of solar power. The power plan also targets a 35% renewable portfolio standard by 2037, which includes 6 GW of solar power.

Since 2007, incentives have been driving solar growth through an Adder paid per kWh generated, which has now been replaced by a feed-in tariff. Rooftop solar for residential use has been made legal since 2015. The law enabled solar users to connect to the grid; hence, a shift from a net metering system to self- consumption has been witnessed within the sector. In 2016, a net metering pilot project allocated 50 MW of solar capacity regionally. The country has also initiated a program for community ground-mounted solar that reserves 800 MW. The total capacity from ASEAN countries is 5.4 GW; hence, if Thailand meets its targets, it is likely that its solar capacity will be more than 60% of that of ASEAN countries.

Hotels are a major challenge in cities like Bangkok due to their height. In such areas, there is a problem of increasing tariffs as well as a lack of rooftop solar potential. The best solution is self-consumption along with storage, which is suitable for daily cycling. Evening peaks are common during summer; hence, some regions have started restructuring tariffs to encourage storage. The same approach could be adopted by Thailand to reduce evening peaks.

Wind Energy Potential

Thailand has 63 coastal provinces where wind power is technically feasible. The Er-Ro-Ver wind map indicates that Thailand has a total wind power potential of about 4,755 MW with a range of 6 to 8.9 m/s. This range is deemed sufficient to produce electricity economically (Peerapong & Limmeechokchai, 2016). However, no commercial wind power projects have been rolled out in Thailand to date. The Public Electricity Authority of Thailand, or EGAT, has been exploring a 3 MW wind power hybrid demonstration plant using wind power and solar power in Kanchanaburi Province. Additionally, a 3 MW wind Power/PV/Diesel hybrid demonstration project is being considered in Phetchaburi. There is also a proposal to set up a 1 MW wind power plant in Sattahip, Chon Buri. Due to its climate, small-scale wind power is deemed suitable for local communities in Thailand. However, small-scale wind power is not readily applicable to hotel businesses due to a lack of leads (Tongsopit et al., 2024).

Energy Efficiency Technologies

Energy efficiency technologies help hotels reduce energy consumption and achieve nearly zero-energy buildings. Hotels are considered nearly zero-energy buildings, denoted by Hotels NZEB, owing to high energy consumption. Hotel renovation to achieve nearly zero-energy buildings reduces costs, improves energy security, and meets market and customer demands. Hotels consume a considerable amount of energy and water, thus requiring specific attention. Energy efficiency technologies help reduce CO2 emissions by a significant amount in the hotel industry. Building technologies help reduce energy consumption and use local renewable energy sources. Heating, ventilation, and air conditioning technologies reduce electricity and fossil fuels. Advanced metering technologies, with the help of sensors, help manage energy and water consumption and detect areas of inefficiency. Efficient building envelopes help reduce cooling and heating loads.

V. STRATEGIC ROADMAPS FOR TRANSITION

The key technology options are influencing the pathway to net zero emissions for the hotel sector in Thailand from 2030 to 2040. The technology options are responsive to the hotel sector because they are adaptable to the way the hotel sector operates. The policy roadmap links the emissions reduction targets to the Sustainable Tourism Goals in Thailand by providing milestones to drive the

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transition, the enabling factors to facilitate the transition, and the indicators to measure the transition. A decarbonization pathway provides a framework on how to normalize carbon budgets, how to quantify the required mitigation effort, how to coordinate the offsets, and how to facilitate the transition cycles that measure the emission reductions for all hotel types from 2030 to 2040 (Chan & Sopian, 2022). The roadmap for the technology options includes solar photovoltaics, wind power, and improving the efficiency of the energy supply because they are common to all hotel types. These technology options can reduce emissions by 21% to 32% without compromising the quality of services. To facilitate the transition to these technology options, the following milestones are proposed: 2024 — expand the Sustainable Tourism Goals for the hotel sector to include the equipment suppliers. It is proposed that technology transfers be encouraged and the sale of products that are carbon-intensive be regulated. 2025 — the hotel sector must be required to improve the efficiency of the energy supply. It is proposed that the tourism infrastructure be linked to the decarbonization programs. 2030 — zero emission certification and improved emissions control to facilitate the climate pledges. These objectives are likely to enhance market transparency, reduce investment risk, raise awareness among the public, and boost market confidence.

Short-term Strategies (2023-2025)

Short-term plans play an important role in Thailand's hotel industry, particularly in its journey towards going net-zero from 2023 to 2025. These plans are centered on six technologies: solar PV, onshore wind, ground source heat pumps, high-efficiency chillers, direct expansion air conditioning, and energy management systems, all in support of achieving sustainable tourism. Scenario analyses have been conducted on three types of hotels: Motel, Limited-Service, and Full-Service, in top destinations like Phuket, Chiang Mai, and Bangkok. From the results, there is an evident decrease in greenhouse gases from 2023, along with an improvement in energy efficiency.

Medium-term Strategies (2026-2030)

A shift towards decarbonisation and net-zero emissions within Thailand’s hotel sector could result in enhanced competitiveness as a tourist destination. Achieving net-zero emissions targets and sustainability remains a major priority alongside overcoming the effects of COVID-19. The research will explore strategies to achieve net-zero emissions targets by 2030-2040 within Thailand’s hotel sector by utilizing models that align with Thailand’s Sustainable Tourism Goals indicators.

Emissions require targeted action, which starts with solar technology that is readily available and aligns with short-term needs. In addition to this, mitigation strategies like wind power and efficiency provide opportunities for short- to medium-term implementation. These strategies are then planned for implementation from 2021-2040.

Long-term Strategies (2031-2040)

The long-term plans for 2031-2040 will be dedicated to fine-tuning how hotels in Thailand use technology in reducing emissions. This will be achieved through customized strategies that consider the special conditions in Phuket, Chiang Mai, and Bangkok. This will involve constant review and evaluation of how these regions are progressing in implementing new technologies that are available. Prioritization will be made in balancing emission reduction, economic viability, and alignment with other elements of the Sustainable Tourism Goal, including STG (Sun et al., 2020). This will ensure that signals from policy can accelerate investment and support the growth of the industry sustainably, as proposed in Masoud Sajjadian (2023).

VI. IMPLEMENTATION FRAMEWORK

The country of Thailand aims at achieving a net-zero vision in tourism by the year 2050, with the Sustainable Tourism Goals (STG) acting as a guiding framework in reducing greenhouse gas emissions in the tourism sector. This report provides a quantitative overview of greenhouse gas emissions in the hotel industry and outlines a strategic plan towards achieving a net-zero vision in the sector by the years 2030 and 2040. It combines two benchmark threads: gross sustainability-linked bonds (g-SLB) and Sustainable Tourism Goals (STG), with both providing investment criteria and KPIs. It focuses on four major greenhouse gas emissions: transport, electricity, heating and cooling, and wastewater treatment, which allows for in- depth scenario testing. These three cities in Thailand—Bangkok, Phuket, and Chiang Mai—are major tourism hubs with unique greenhouse gas emissions, which help in choosing the right technology and methods in reducing carbon emissions. The hotel industry requires high capital investment and relies on specific performance indicators such as the number of boilers installed and renewable heat production to ensure net-zero compliance. Although there is sufficient evidence of the feasibility of a net-zero vision, the lack of full comparability of the various benchmarks used makes it hard to replicate the results uniformly.

Stakeholder Engagement

To accelerate Thailand’s hotel industry towards achieving net-zero emissions between 2030 and 2040, a proposed timeline has been developed that aligns with Thailand’s Sustainable Tourism Goals. Based on STG frameworks, there is a proposed stakeholder engagement mechanism that identifies who does what and how they can work together in collaboration with hotels, industry groups, government bodies, and local communities.

There are roles assigned depending on the size and type of organization. Large and specialized hotel operators have roles in roadmaps, technology spread, investment, and carbon accounting, where they provide essential information. These industry groups have roles in steering

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roadmaps, drafting briefing materials, communication on policy, and information sharing. Government bodies have roles in target setting, benchmarking, legislation, and incentives. Provincial bodies have roles in monitoring, compliance, and supporting startups and operations. This dynamic, open, and collaborative platform enables increased ambition and raises the public profile of coordinated industry-wide action (Caixach, 2015).

Policy Alignment and Support

The importance of the hotel sector to Thailand's economic development and its international reputation means that making emissions equal to zero has to be a top priority. Two areas are important to consider. One is that we need a roadmap that will help hotels across Thailand achieve net zero emissions between 2030 and 2040. The different sources of emissions in Phuket, Chiang Mai, and Bangkok, as shown in Exhibit 3.2, mean that we need to provide a technological direction that focuses on solar and wind power technologies, as well as short-term, medium-term, and long-term roadmaps using digital technologies.

The other area is that we need to provide operational performance indicators that 1) can be used to monitor national-level progress and 2) provide a management system that monitors Sectoral Greenhouse Gas Emissions as well as the related KPIs of the Sustainable Tourism Goals (STGs). These national-level roadmaps and emission models must align with Thailand's STGs that provide greenhouse gas emission targets (NDC|NAMA) for the hotel sector. Under the STG system, the current allocations of emissions for various countries have already been defined by sector to advance sustainability. The operations must be balanced between business viability and sustainability to ensure that they remain within international targets.

Funding and Investment Mechanisms

Capital financing is a major challenge for implementing improved energy efficiency, renewable energy projects, as well as other decarbonisation strategies. Government funding is only part of the solution; a proper transition strategy has to align with the Nationally Determined Contributions (NDC) process. The implementation of transition strategies that are aligned with NDC strategies is easier; it becomes simpler to report greenhouse gas mitigation activities. The process reduces transactional costs as well (Grace J. Saculsan & Mori, 2018).

Environmental funds have become a vital entity for backing investments that are necessary for the structural change of the sector. These funds are usually channeled through schemes that ensure economic sustainability as well as environmental sustainability. The government establishes a coordination mechanism with the private sector to implement economic policies. The funds deal with various environmental concerns such as waste management strategies, alternative energy strategies, improvement of energy efficiency strategies, management of water resources, chemical hazard prevention strategies, strategies for a green economy, adaptation strategies, as well as strategies for recovering from natural disasters. From an environmental accounting point of view, it is a policy tool that is necessary for dealing with the increase in emissions that results from rapid growth in the tourism sector. Environmental funds are a deliberate financial vehicle that is necessary for backing investments aimed at improving energy efficiency as well as demand reductions such as replacing equipment, implementing clean technologies, as well as embracing alternative or renewable energies within hotels.

VII. PERFORMANCE TRACKING AND REPORTING

The post-implementation assessment is an essential role in evaluating the extent to which the roadmap has been implemented and the speed at which net-zero technology is being deployed. With better performance monitoring tools, it becomes easier to identify the areas that have deviated and develop strategies to bring them back on track. The key performance indicator is based on Sustainable Tourism Goals (STGs) 1-6 and 8, which emphasize reducing emissions in hotel operations. The assessment framework consists of two parts: the generation of renewable energy based on STGs 1, 2, 3, and 8; and the use of renewable energy based on STGs 4, 5, and 6. The generation system always monitors the data in real time, which helps in continuous and long-term assessment. The use of renewable energy is based on the percentage of renewable and non-renewable energy use, and if it reaches 100 percent renewable use, it implies net-zero emissions. This method uses numerical values and national benchmarks and provides an accurate and step-by-step view of the entire process. (Nocera et al., 2019)

Key Performance Indicators (KPIs)

Key Performance Indicators (KPIs) enable a clear and standardized understanding of how strategies are being implemented. The achievement of net-zero in the hotel industry in Thailand is dependent on the achievement of key KPIs in sustainability targets set by Thai SDG Progress Indicators. These KPIs must be supported by the net-zero strategy roadmap. The major KPIs set by STG that can be impacted by a net- zero strategy roadmap quantitatively are those related to energy and fuel usage. These include STG 8.4.1c: "Share of sustainable tourism activities within total activities," STG 11.6.2a: "Share of hotels using energy- saving technologies," STG 12.2.1a: "Amount of recycled solid waste generated by hotel industry," STG 12.7.1: "Share of establishments that adopted eco-friendly technologies," and STG 12.c.1: "Share of establishments that were equipped with environmentally sound technologies" (Ba et al., 2022). To monitor the achievement of net-zero, these KPIs are related to a set of core KPIs used for monitoring and

reporting purposes. Using the KeNEx model, strategy success in achieving net-zero emissions in the hotel industry is monitored through the development of integrated models.

Monitoring and Evaluation Frameworks

However, a wide deployment of core technologies and a detailed roadmap with clear milestones are required to achieve net-zero emissions in the hotel industry in Thailand. A monitoring and evaluation system would be beneficial for the hotel industry in Thailand to achieve the transition to net-zero emissions smoothly. This system would help the industry measure the efficiency of the pathways, making them more practical and viable, and thus facilitating a smoother transition. We may consider the Net-Zero Hotel Industry Roadmap as a foundation for developing the monitoring system.

Since the net-zero pathways are in line with the Sustainable Tourism Goals, the monitoring system would help measure efficiency by tracking the KPIs related to these Sustainable Tourism Goals. This monitoring system would be based on scientifically verified data and would be reviewed regularly as the pathway progresses. This would help us understand how the active efforts are influencing the pathway by comparing the efficiency of decision-making tools with the net-zero KPIs. This would also help identify deviations and areas where corrective action is required. Once we have the KPIs in hand, it would be easier to implement corrective action and plan further measures based on the information provided by the KPIs. This would also help with conducting efficient checks and thus provide a reliable system for assessing the pace and reporting for review.

The monitoring and assessment system would require clear inputs and indicators. We may also consider additional data related to climate mitigation and adaptation, climate governance and structures, and community resilience. While tracking greenhouse gas emissions on a global scale, the KPIs for these emissions must be defined. In the same way, greenhouse gas emissions in the hotel industry may be tracked by considering the KPIs related to the Sustainable Tourism Goals.

VIII. CASE STUDIES

The Scaling Solar project in Zambia is a good example of a project that has good potential in identifying the problems that might cause delays, as well as provide a solution and encouraging others to adopt the method. The following are examples of how the SBTi net zero guidance is being put into practice in Thailand's hotel industry.

Sustainable Destinations, Thailand

Since 2014, Sustainable Destinations has completed over 250 international certification audit assignments. Their online tool, called the Sustainable Destinations Evaluator, is based on best practices from the Global Sustainable Tourism Council, Green Globe, and the Travelife Standard. This forward-thinking tool considers 13 sustainability indicators that are relevant to the activities of the Tourism Authority of Thailand. Destinations all over the world can use it to monitor and improve their sustainability performance. The Sustainable Destinations Evaluator is also useful for Tourism Management Organizations (TMOs) that need a solution for managing the certification process and monitoring sustainable development.

Tourism and the Sustainable Development Goals – Journey to 2030, United Nations World Tourism Organization (UNWTO)

The UNWTO report recognizes the importance of tourism in the success of many of the Sustainable Development Goals and the role that it will play in the global Agenda 2030. Without cooperation and interaction between the public and private sectors, the motivation for sustainability will be lacking. Therefore, the challenge is how all the players in the tourism industry will cooperate towards a better and more sustainable tourism development. Achieving the Sustainable Development Goals will require business operations and marketing strategies respect and embrace the environment, society, and culture.

Successful Net-Zero Initiatives in Thailand

The key to net-zero efforts is the combination of policy, institutions, and technology all working together to reduce emissions in the context of climate change. The way Thailand approaches the concept of low- carbon collaboration is through the development of green power sources such as solar and wind power and assessing how they might be integrated into hotel operations in Phuket, Chiang Mai, and Bangkok before they are deployed. The objective of net-zero emissions by 2065 is based on 17 Sustainable Tourism Goals (STGs) and a Strategic Energy Plan that provides a framework in alignment with the United Nations Framework Convention on Climate Change. The country's roadmap is designed to reduce greenhouse gas emissions from the tourism sector by a significant amount by 2030 (Pita et al., 2020).

International Best Practices

The concept of responsible tourism has become an essential policy imperative in various countries. Leaving the tourism sector too early will be challenging. Therefore, it is important to rethink and enhance the tourism sector by incorporating environmental care and quality of life. The use of energy by hotels and the resulting CO2 emissions in Thailand contribute to a significant percentage of the total emissions. The percentage is about 1% (Pita et al., 2020). The tourism sector is tasked with the role of contributing

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to the reduction of emissions globally. The Enhanced Thailand Tourism Strategy has set targets of net-zero and reduction targets for hotels. Additionally, it has set out a five-year plan to reduce hotel-made emissions by 20%.

Hotels can attain the targets set by the government and the international community by embracing green and sustainable technology. The design of energy-efficient hotels is an emerging international trend. The design of energy-efficient hotels differs according to the capacity of the hotel. A hotel consists of six main areas. They include bedrooms, the restaurant and kitchen area, conference facilities, lobbies and street- facing areas, the laundry area, and the remaining service areas (Caixach, 2015). Hotels that have large capacities tend to use more energy. Hotels in Thailand use solar and wind energy generation and energy- saving mechanisms. The electricity produced comes from the energy produced by solar and wind energy generation installed. Additionally, energy-saving mechanisms include energy-efficient lighting, cooling, heating, ventilation, and control systems.

IX. CHALLENGES AND BARRIERS

However, financial barriers are a major challenge in the hotel industry in Thailand in terms of adopting a net-zero approach. First, the high financial costs of renewable technology and improving energy efficiency may prove to be a major hurdle in the hotel industry in Thailand in terms of adopting a net-zero approach. Similarly, there may also be a lack of technical support services in the hotel industry in Thailand in terms of adopting a net-zero approach. For example, small and medium-sized businesses may not have the necessary expertise in choosing the right technology in terms of a net-zero approach. Similarly, regulatory and administrative barriers may also prove to be a major challenge in the hotel industry in Thailand in terms of adopting a net-zero approach. For example, there may be a lack of financial incentives in the hotel industry in Thailand in terms of adopting a net-zero approach. Similarly, there may also be a lack of regulatory frameworks in the hotel industry in Thailand in terms of adopting a net-zero approach. Likewise, a lack of mandatory standards and certification may also prove to be a challenge in the hotel industry in Thailand in terms of adopting a net-zero approach. Similarly, a lack of sufficient data collection and analysis may also prove to be a challenge in the hotel industry in Thailand in terms of adopting a net-zero approach.

Therefore, to overcome these hurdles in the hotel industry in Thailand in terms of adopting a net-zero approach, a multi-faceted effort may be required soon. For example, financial instruments may be developed in the hotel industry in Thailand in terms of adopting a net-zero approach. Similarly, administrative processes may also be streamlined in the hotel industry in Thailand in terms of adopting a net-zero approach. Likewise, regulatory frameworks may also be put in place in the hotel industry in Thailand in terms of adopting a net-zero approach. Similarly, sufficient technical support services may also be provided in the hotel industry in Thailand in terms of adopting a net-zero approach. Likewise, sufficient data management systems may also be provided in the hotel industry in Thailand in terms of adopting a net-zero approach. All these factors may help the hotel industry in Thailand in terms of adopting a net- zero approach soon (Nocera et al., 2019

Financial Constraints

The financial constraints are slowing down Thailand's hotel industry in its path to net zero, even with the best efforts already in place. Previous research has been dominated by statistics without sufficient on- ground data. This highlights the requirement for strong quantitative carbon emission models to be aligned with Sustainable Tourism Goals (STGs), particularly for those hotel subsectors that are critical to Thailand's tourism industry and whose strategies are yet to be significantly impacted from 2030 onwards. The barriers highlighted are those related to efficiency gaps, cost barriers, technology feasibility, and stakeholder engagement. These barriers are indicative of how entrenched these barriers are to any long- term decarbonization strategies (Nocera et al., 2019). Thailand's hotel industry is dominated by small and medium-sized enterprises (SMEs), who are under intense competition from similar-sized peers and larger international hotel groups. This is particularly highlighted by the well-established emissions profile relative to other building types. For hotel operators to invest in more capital-intensive equipment under financially constrained conditions, high returns are required. Sustainable Tourism Goals and decarbonization strategies are set to ensure a deliberate path to net zero from 2030 to 2040. Strategic roadmaps provide a framework for implementing accessible technology by integrating solar, wind, and efficiency into a single strategy that is tailored to specific KPIs that provide actionable recommendations for prioritizing options. The work promotes more effective engagement by establishing measurable timeframes that convert long- term goals into actionable steps. The work is intended to inform iterative implementation and re-alignment with existing data and policy tracks.

Energy profiles provide a means to calculate emissions profiles by location for all major types of hotels. The research targets three representative areas of commercial activity: Phuket, Chiang Mai, and Bangkok. Phuket and Chiang Mai are resort-style operations that are primarily composed of independent hotels and mid-scale branded chains. In contrast, Bangkok represents business-style operations that are primarily composed of branded hotel groups. Technology is directly related to existing sources of energy and demand patterns, which are expressed as relative potential and political constraints in numerical form. Solar and wind potential vary significantly from one

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area to another, as national targets are established at different levels as reported by Guanxiong, Micael, & Yulong (2019). PV has the highest potential of all sources, which is expressed as several hundred megawatts per area depending on existing architectural features.

Technological Limitations

Several research findings also show that hotels could minimize their energy consumption and emissions by embracing new technology. Spas and wellness centers use a lot of energy for heating and various processes. Heat pump technology is an important technology that could address the thermal energy challenges and minimize emissions. Heat pump technology could be more efficient in heating and cooling compared to other conventional heating and cooling systems. Moreover, it could be more efficient if it uses renewable energy sources such as solar and wind power. This could minimize the use of fossil fuels. There are two main ways that could minimize emissions and energy consumption in the hotel sector. One of them is the use of low-carbon electricity generation. The second option is the use of low-carbon heating and various thermal energy alternatives instead of using fossil fuels. Solar power is an important technology that could be employed as an alternative source of electricity. Its potential could be consistent with the energy efficiency and renewable energy targets set by the government. Several factors could be considered if more solar PV needs to be installed. For example, the technical potential of DPV was about 208,409 MW in 2019. However, it could increase to 226,373 MW by the year 2037. On the other hand, the economic potential of DPV could be about 9,794 MW by the year 2037. Additionally, the market potential could be about 9,267 MW. The economic potential could not be higher than the technical potential. Moreover, it could be influenced by the capacity of the power grid. Several small power plants could be more efficient in maintaining the power grid compared to large power plants. On the other hand, wind power could be an important alternative source of electricity. The technology could be efficient because of the availability of wind power. The lifecycle emissions of technology could be higher compared to solar power. However, it could use about 40% of the space that solar power uses. The technology could also be efficient in improving energy efficiency. Gas boilers could emit more compared to electricity produced using natural gas and renewable energy. By using low-carbon electricity generation, more emissions could be minimized. (Tongsopit et al., 2024)

Regulatory Hurdles

Thailand's desire for a more renewable energy-based system is challenged by regulatory hurdles that affect the rate at which renewables are dispatched by power utilities (Pita et al., 2020). The rate at which net- zero technologies are adopted is affected by this. For net-zero technologies to be adopted more fully, better policy integration is necessary within the power sector. In the case of hotels, Sustainable Transformation Goals could be a major enabler to help circumvent some of these challenges and hasten Cambodia's transition.

X. FUTURE DIRECTIONS

New wave technologies are emerging that are creating new avenues for reducing the carbon footprint of the hotel industry. In coastal destinations like Phuket, wave technology has shown great potential as a source of clean energy by harnessing it from sources like oscillating water columns, point absorbers, attenuators, and overtopping devices (Nocera et al., 2019). Third-generation PV technologies are also emerging as a new source of clean energy. These are ultrathin PV technologies that are efficient, flexible, and light in weight. These are easy to incorporate into existing structures of hotels. In areas that are windy, hybrid turbine technologies are also a new wave that is creating new avenues for harnessing wind as a source of clean energy when it is plentiful (Masoud Sajjadian, 2023). New innovations like velocity sensors, low-power computer chips, and software are creating new avenues for better estimates of turbine output, which is a great economic opportunity. A more targeted policy could help accelerate this new wave of clean technologies to achieve Sustainable Tourism Goals (STGs) targets.

Innovative Technologies on the Horizon

The hotel industry is one of the biggest consumers of energy in Thailand's tourism industry. The industry mainly consumes electricity, diesel, and petrol. There has been research on how emissions intensity looks and has mapped out net zero strategies from 2030 to 2040 to achieve Sustainable Tourism Goals (STGs). This analysis has been carried out to identify new technology that could be used to achieve decarbonization strategies for the hotel industry. The new technology that could be used to achieve decarbonization strategies for the hotel industry is photovoltaic solar power, solar water heaters (both thermal and photovoltaic), and wind power. These technologies could reduce the existing energy consumption by up to 44%, 11%, and 31% respectively. There are other strategies that could be adopted to achieve decarbonization strategies for the hotel industry. These include District Cooling Systems (DCS), Combined Heat and Power (CHP), Voltage Optimization, and lighting and appliances upgrades, building management systems upgrades, insulation upgrades, and glazing upgrades. Of these strategies, DCS, CHP, Voltage Optimisation, and energy efficiency upgrades are cost-effective strategies with high returns on investment (Caixach, 2015).

Policy Recommendations for Sustainable Growth

The Thai hotel industry is on track towards achieving net-zero emissions, guided by scenarios that are aligned with the Sustainable Tourism Goals (STG). This is because, by identifying the exact source of emissions, it is easy to create an outline that guides the reduction pattern. This, in

turn, shapes the adoption plan and outlines the decarbonization pathway. Solar, wind, and energy-efficient technologies are at the heart of pushing the industry towards more aggressive goals. Strategic roadmaps are in place, guiding the industry towards achieving net-zero emissions between 2030 and 2040, while rate-based KPIs track the industry's progress towards achieving the Thai Sustainable Tourism Targets (Ba et al., 2022).

XI. CONCLUSION

The realization of net zero in Thailand's hotel industry will require the development of national roadmaps that incorporate Sustainable Tourism Goal KPIs with the means of adapting new technologies. The hotel industry is currently at a point of 0.6 MtCO2-eq in energy-related emissions, and with the adoption of solar power, wind power, and better usage of energy, it can reduce emissions by as much as 75.1–94.7% by the year 2040. The national roadmaps will incorporate a step-by-step technology adoption plan that matches short-, medium-, and long-term emission reduction goals. Solar power and better usage of energy will be responsible for the initial reduction in the period from 2025 to 2030, while wind power will be responsible for a greater reduction from 2030 to 2040. The realization of this will, however, require the cooperation of major stakeholders and the backing of investments through the Green Hotels and Tourism Incentive Program. This transition of hotel energy usage from traditional sources of energy to on-site solar and wind power will be a significant step towards the realization of Net Zero, as it will provide a framework for a net zero transition that is consistent with the Paris Agreement. (Nocera et al., 2019) (Pita et al., 2020) (Fahy, 2010)

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