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Environmental Management and Green Practices in the Construction Industry Across ASEAN Countries: A Comparative Study

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ABSTRACT: The construction industry in Southeast Asian countries especially Association of Southeast Asian Nations receive substantial attention and investment for the high return value of the industry. This review aims to assess the environmental impact of the construction industry in ASEAN countries, analyzing current status, government policies, and innovative green materials and technologies to mitigate environmental effects and promote sustainability. It is important to note that construction industry is currently identified as one of the greatest waste production businesses which can cause adverse impacts and pollution to the environment that degrade the environmental quality. Construction and demolition wastes are emphasized and studied in the following context. The status and government policy on environmental management practices in ASEAN countries such as Malaysia, Vietnam and Singapore are reviewed and summarised in this article. Furthermore, green construction materials and green material technologies that are practised in ASEAN countries are examined throughout the study. The green materials include bamboo, recycled concrete aggregate, coconut husk and bagasse while the green material technologies include hydrogen energy, carbon capture and storage, and solar energy are discussed and evaluated with respective advantage and disadvantages.

KEYWORDS: Environmental management practice; green technology; green material; sustainable construction; ASEAN

1. Introduction

Construction is defined as an activity within the engineering branch of production and an industrial process that encompasses building, renovating, restoring, repairing, and retaining structures [1]. The construction industry is pivotal to a country's advancement in technical and technological aspects, as it is frequently undertaken to regulate infrastructural growth and ensure sustainability. It is anticipated to continuously develop in projects involving housing, manufacturing plants, high-rise buildings, irrigation, transportation facilities, and infrastructure, playing a significant role in contributing to and stimulating economic growth and socio-economic development [2, 3].

The construction industry in Southeast Asian countries, especially the Association of Southeast Asian Nations (ASEAN), attracts substantial attention and investment due to the industry's high return value. For example, the construction sector in Indonesia is recognized as the largest in the ASEAN region and ranks fourth globally [4]. In the fiscal year of 2014, Indonesia's construction industry contributed approximately USD 267 billion, surpassing other ASEAN countries, including Thailand (USD 33 billion), Malaysia (USD 32 billion), the Philippines (USD 25 billion), Singapore (USD 24 billion), and Vietnam (USD 16 billion) [4]. The significant economic contribution from the construction industry plays an essential role in stimulating economic growth and the development of a country. The entire construction process stimulates the economy by providing career opportunities for the local society and offering outcomes, including public infrastructure and building structures, for the local community to engage in productive activities in the fields of utility, trade, industry, and service. Nevertheless, government policy and strategy are known to have a great influence on regulating the economy, allowing for the construction of public works during periods of stagnation [5]. It is crucial to note the profit rates and risks associated with the construction process, given the considerable variation in each country, especially in Southeast Asia. A comparison of profit rates and risk indexes among ASEAN countries in the year 2016, such as Singapore, Indonesia, Thailand, the Philippines, and Malaysia, is illustrated in Table 1.

Table 1. Profit rate and risk in ASEAN counties in 2016 [4].

Country	**Profit rate**		**Risk**	
	Construction	**Country**	**Construction**	**Country**
Singapore	37.5	86.2	90.0	83.2
Indonesia	65.0	48.2	35.0	59.6
Malaysia	50.0	64.3	55.0	60.5
Vietnam	52.5	60.4	40.0	60.0
Thailand	42.5	72.3	50.0	58.9
Philippines	50.0	55.1	35.0	64.0

Note: Lower risk is represented by higher risk score

From Table 1 above, it can be concluded that Indonesia presents the highest risk in the construction industry while Singapore presents of that of the lowest risk in the construction industry. While in term of profit rate, Indonesia, and Singapore present with the greatest and least profit rate respectively. Nonetheless, it is important to note that construction industry is currently identified as one of the greatest waste production businesses [1]. The objective of this review paper is to comprehensively assess the environmental impact of the construction industry in Southeast Asian countries, particularly within the Association of Southeast Asian Nations (ASEAN), by examining the current status, government policies, and innovative green construction materials and technologies, with a focus on mitigating adverse environmental effects and promoting sustainable practices.

2. Current Status and Government Policy on Environmental Management Practices

2.1. Malaysia.

The status of the construction waste management initiatives in Malaysia is known to be encountered challenges in effectively and efficiently implementing appropriate approaches to acknowledge and address the illegal and improper construction waste management issues [6].

The daily solid waste generation in Malaysia is estimated to be approximately 25600 tonnes due to the rapidly growing urbanisation and development within the nation [7]. It is important to note that the emphasis on the construction waste management is only introduced and implemented by Malaysia in the year of 2006. Previously, there was an absence of the specific and construction waste management guidelines and system but only abundant of solid waste management system within the nation. The implemented solid waste management policies include National Strategic Plan on Slid Waste Management 2005, National Solid Waste Management Policy 2006, Solid Waste and Public Cleansing Management Act (Act 672) 2011 [8, 9]. Furthermore, an approach themed as Reduce, Reuse and Recycling (3R) is implemented in the 8th Malaysia Plan during the period of 2001- 2005. These initiatives are introduced and established by the governmental agencies which require collaborations from the local authorities and private industries to perform comprehensive waste management system to minimise the waste quantity. In the year of 2005, National Strategic Plan for Solid Waste Management is established as the solid waste management policy in Peninsular Malaysia which is executed until the year of 2020.

Moreover, additional effort from the government to encourage the implementation of waste management could be observed through the enactment of the legislation and regulations such as Solid Waste and Public Cleansing Management Act (Act 672) which is enforced by the two federal institutions including National Solid Waste Management Department and Solid Waste Management and Public Cleansing Corporation. The main objective of the agencies is to attain a recycling rate of at least 22% of the waste by the end of the year of 2020. Thus, the 9th Malaysia Plan that implemented during the year of 2006- 2010 has continued to integrate the concept of 3R with the idea of recovering into the existing waste management system. Construction Industry Master Plan (CIMP) was first launched in the year of 2006 to aim to enhance the environmental performance of the construction industry for a period of ten years. Interestingly, the enhancements on the quality of the work, environmental practices, safety, and health are highlighted by the Strategic Thrust No.3 of the plan which aligns with the Guidelines on Construction Waste Management established by the Construction Industry Development Board (CIDB) to improve the environmental performance of the construction industry. However, the efforts are failed to be supported with legal enactment and enforcement. As a consequence, different waste management system are applied among the local contractors due to the absence of a standardised waste management approach. To further improve the current waste management system in Malaysia, CIDB again established the Construction Industry Transformation Programme (CITP) in September 2015 as the continuation of CIMP to provide uniformity and continuity with the national agenda in fulfilling the stated thrusts in the 11th Malaysia Plan. CITP focuses on four different elements including quality, environmental sustainability, internationalisation, safety and professionalism to achieve the goals [10]. Nonetheless, efforts and collaborations from all the involved parties are required to perform a standardised and effective waste management system to improve the current situation in Malaysia.

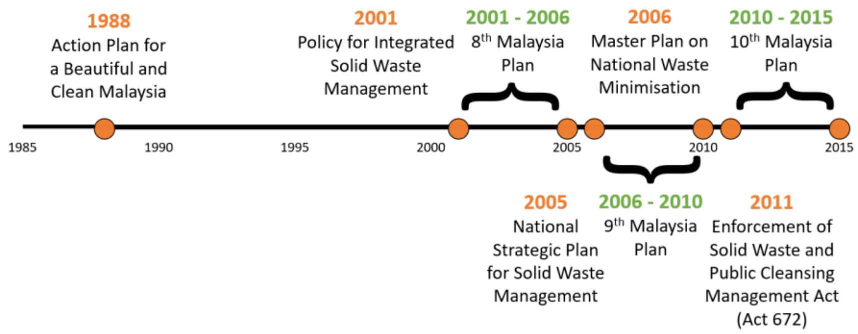

Figure 1. Timeline of implemented EMPs in Malaysia.

2.2. Vietnam.

It is known that several public policies are implemented in Vietnam to enhance the municipal waste management system. However, no significant improvement is observed on the status of waste management system. Public policy is frequently referred as laws, legislations, regulations, constitutions, directions or principles which is commonly used as a management tool during the implementation of governmental action plans [11]. A summary of the domestic solid waste management system in Vietnam is listed in Table 2.

Table 2. Implemented EMPs in Vietnam.

Category	**Policy**	**Year**	**Enforcement Agency**	**Description**	**Ref.**
Strategy	Solid waste development strategy in urban areas and industrial parks in Vietnam	1999	Prime Minister of Vietnam – Ngo Xuan Loc	The main objective of the strategy is to achieve a recycling and recovery rate of 80% to 95% of the total produced solid waste in urban areas and industrial regions.	[12]
National program	Solid waste treatment investment program for the period 2011-2020	2011	Prime Minister of Vietnam – Hoang Trung Hai	The aim of the program is to attract more investment in the field of solid waste management treatment to enhance the status in terms of efficiency	[13]
Decision	Announce the norm of municipal solid waste collection, transportation and treatment	2014	Ministry of Construction	The decision emphasizes on the implementation of the regulations on waste collection and transportation, street sweeping, and treatment of solid waste	[14]
Law	Law on Environmental Protection	2014	National Assembly of Vietnam	The establishment of law is to provide guidelines for environmental protection activities including resources, measures, and policies.	[15]
Decree	Decree on waste and scrap management	2015	Vietnamese Government	The establishment of the decree is to act as standard in waste management including hazardous, domestic and industrial wastes	[16]
Strategy	National strategy on integrated solid waste management to 2025, with a vision to 2025	2018	Prime Minister of Vietnam – Trinh Dinh Dung	The primary goal of the strategy is to develop an integrated solid waste management system by the year of 2025 with advanced and appropriate technology to perform waste management approaches	[17]

In the year of 2017, a circular on construction solid waste management namely, Circular No. 08/2017/TT-BXD is established by the Ministry of Construction of Vietnam to act as the guideline in providing appropriate management on the construction waste in Vietnam. The established circular policy is deemed as the first construction and demolition waste-designated legal legislation in ASEAN [20]. Thus, a strategy themed as National Strategy for General Management of Solid Waste to 2025 with vision towards 2050 is issued to target a collection rate of construction and demolition waste of 90% and recycling or reusing rates of that of 60% by the year of 2025 [19]. The common driven of the construction and demolition waste flow in Vietnam is identified as the provided economic incentives under the supervision from the governmental agencies [21].

Generally, the construction and demolition wastes are classified into two primary categories: valuable and non-valuable wastes. Valuable waste is recognised as the reusable and recyclable materials such as brick, wood, concrete, scrap metal. For instance, concrete and brick tend to be collected after the implementation of a construction project to be reused for backfilling at the other construction site. Private industries including craft villages and scrap dealers are often assigned for the collection and treatment of the materials on a contract basis while the informal sectors such as scavengers are frequently involved in the waste collection at the landfills, open dumping sites, and construction sites to trade for a living. Despite that the initial and positive practices of reusing and recycling are exhibited by the activities, an ineffective system is contributed [19]. On the other hand, the non-valuable waste is defined as the material subjects for final disposal. The waste generators are responsible to implement appropriate measures to transport and disposal wastes at the designated disposal sites and landfills to compliant with the legal requirements. Nonetheless, the non-valuable wastes are frequently to be disposed illegally in the inappropriate locations due to the scarcities of legal landfills or dumping areas and poor enforcement of law and regulation. The common illegal dumping areas of construction and demolition wastes in Vietnam is recognised as waterways, vacant land, and kerbside [20].

2.3. Singapore.

Singapore is recognised as the country with high-income economy based on the World Bank income-based development scale [22]. Construction and demolition waste recently receives substantial attention as an environmental issue which requires appropriate management to prevent further environmental pollutions that execrate the current situation. Hence, Ministry of the Environment and Water Resources (National Environmental Agency, Public Utilities Board, Pollution Control Department) is assigned as the primary authority in the solid waste management whilst Ministry of National Development (Building and Construction Authority) is appointed as the primary authority in construction and demolition waste management under the Environmental Pollution Control 1999 and Environmental Public Health Act 2002 [23, 24]. The construction and demolition waste flow in Singapore is known to be more advanced than the ASEAN countries which results in a relatively comprehensive waste management system especially, the construction and demolition waste. Waste segregation is practised to sort out and retrieve the valuable waste prior to the incineration that performed by the waste-to-energy (WTE) plants. As a result, a recycling rate of 99% is achieved in Singapore to recycle the valuable the construction and demolition materials except the sludge and soil over the past few years [25]. Thus, only the waste management sectors that authorised by the Singaporean government are allowed to perform collection and treatment on the construction and demolition wastes that generated by the industrial and commercial industries. The authorised sector is required to familiar with the provided code of practice to standardise the collection and treatment processes to minimise the environmental damage through the appropriate management measures [20]. Singapore aims to develop and transform into a global city with sustainable environment by implementing diverse environmental regulations and initiatives including Sustainable Construction Master Plan 2008, Singapore Green Plan 2012 (SGP 2012), Green Mark Scheme and environmental management system (EMS) to promote sustainable construction within the nation [26]. For example, the construction firms in Singapore are required to adopt ISO 14000 EMS to monitor and enhance the environmental performance of the construction process and to compliant with the requirement of Building and Construction Authority (BCA) [27]. Several combined routine surveillance audits are performed by BCA for the certified construction firms under the ISO 14000 certification schemes to assess and evaluate the environmental and quality performances of the EMS and gradually reduce the number of audits in the future. Nonetheless, the construction firm is required to be examined through various planning and preparation stages to obtain the formal certification to ISO 14001 [28].

3. Environmental Management Practices

3.1. Definition of environmental management practices.

Environmental management practices (EMPs) are described as the appropriate approach that involve environmental procedures and processes to provide training to the authorised personnel on monitoring and controlling the environmental effects for the purposes of assessing, evaluating, and reporting the environmental performance of the supervised activities. The evaluated performance is known to be regularly reported to both internal and external stakeholder of the organisations that implement with the EMPs. Generally, EMPs are categorised into three different groups: operational, tactical, and strategic [29]. It is important to note that the high diversity in implementation method of EMPs to achieve a great range of the objectives and goals through different resources commitments. Nonetheless, it requires additional effort for an organisation to coordinate and integrate operational, tactical, and strategic practices into the operation to achieve the environmental initiative [29]. The definition of each category is summarised in Figure 2.

EMPs are extensively utilized to accentuate on the environmental performance during the transformation of a commercial or industrial activity. It is significant to utilize effective tools to evaluate the environmental performance of an activity due to the associated expenses of the advanced environmental technologies. Furthermore, the presence of the voluntary environmental initiatives such as Business Principles for Sustainable Development of the International Chamber of Commerce (ICC) and ISO 14001 of the International Organisation Standardisation (ISO) promotes the importance of the EMPs and environmental plans [29].

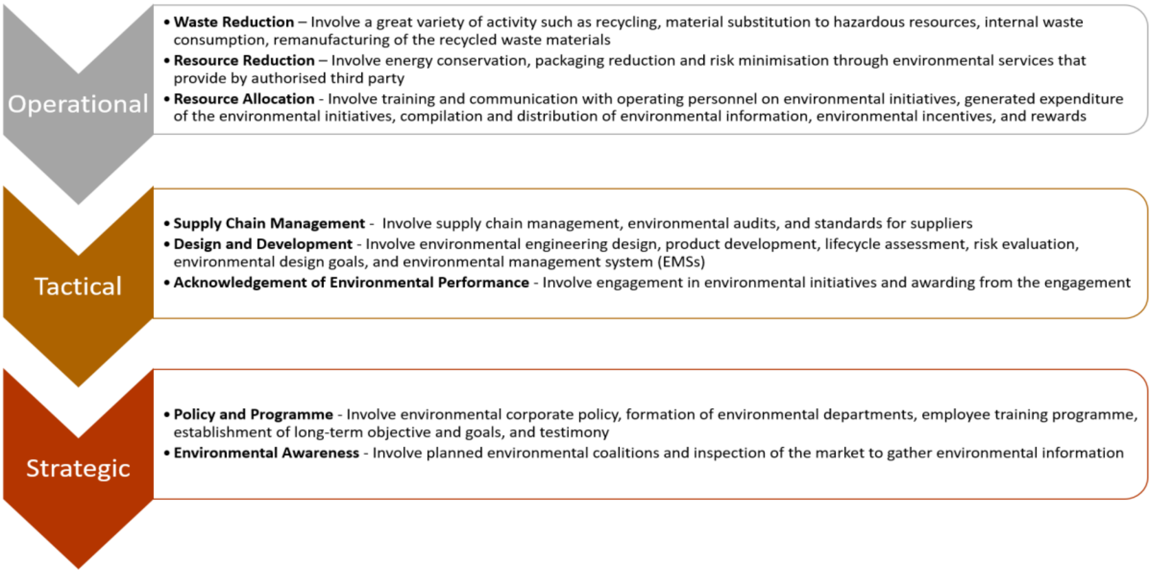

Figure 2. Definition of different EMPs.

3.2. Environmental management practices and sustainable development.

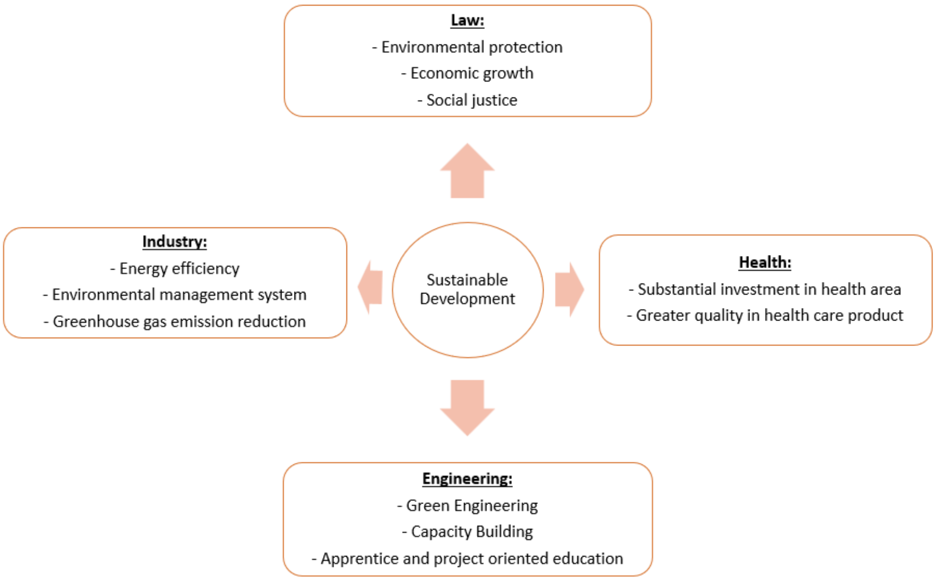

Figure 3. Current framework of EMPs in different disciplines.

According to the Brundtland report, sustainable development is defined as the development that is able to cater the current demand of the society without negotiating with the capability of the future generations to satisfy their own desires. It is known that the sustainable development is closely related to triple bottom lines namely, economic, social, and environmental [30]. Different EMPs are known to be performed across a great variety of disciplines including the engineering, industry, health, and law which could contributes towards sustainable development [31]. The current framework of the EMPs in each discipline is illustrated in Figure 3 while Table 3 indicates the EMPs that are adopted in each discipline with respective impact on sustainable development.

Table 3. Description of different EMPs in different disciplines

Environmental management practices	Impact on sustainable development	Reference
Environmental management		
Water conservation	Reduce water loss from soil and the occurrence of soil erosion	[32]
Water recycling	Promote higher environmental sanitation and produce career opportunities	[33]
Energy efficiency	Promote reduction in energy consumption for a lower carbon footprint	[34]
Carbon emission management	Support the establishment of carbon credit which controls the emission of carbon emission and stimulates the economic growth	[34, 35]
Land management	Establishment of judicious and sustainable land management plan or policy	[36]
Engineering		
Environzmental education	Strengthen public knowledge with sound principles on sustainable development	[37]
Green technologies	Act as an enhancement in sustainable development through advanced technology which promotes green materials and minimal resource extraction	[38]
Sustainable construction procedure	Promote the utilisation of green materials in the construction project to reduce the carbon footprints and to decrease overall expenditure	[39]
	Industry	
Water efficiency	Improve higher accessibility to safe water resources and food security	[40]
Energy efficiency	Encourage planned energy usage to lower the emission of environmental contaminants	[41]
Cleaner manufacturing process	Produce and provide sustainable and green products or services through cleaner manufacturing process	[42]
	Health	
Green building construction	Construct green buildings to create a comfortable and harmony working atmosphere	[43]
Sustainable health care	Increase the efficiency of the utilised health care services and energy for sustainable health care	[44, 45]
Investment in health care facilities and technologies	Attract investment and funding in health care facilities and technologies to provide comprehensive and effective health treatments	
	Law	
Establishment of environmental policy	Promote the establishment of environmental policy to strengthen the environmental compliancy	[46]
Establishment of penalty and fine	Introduce penalty and fine as an enforcement for organizations to comply with existing environmental regulations	[47]
Establishment of international standards	Encourage the adoption of international standards among the organisations for sustainable development by acknowledging the benchmarks in environmental management	[48]

4. Current Situation of Green Construction Materials

4.1. Bamboo.

Bamboo, as an important non-timber forest resources, has been introduced as construction material due to its characteristics of high strength, availability, and workability [49]. Interestingly, the tensile strength of bamboo is discovered to be similar with steel at approximately 28000 N/m^2 equivalent to 0.025 MPa [50]. It is considered as a green construction material as it results in relatively more positive environment impact compared to other construction materials. The renewability of bamboo is considered as high in which the harvesting of it can be performed after 3-4 years after the plantation and annually after that [49]. Hence, bamboo is emerged as an alternative to sold wood material or timber to reduce the pressure acted on the limited forest resources. The application of bamboo as the primary construction material could be observed across the Southeast Asia. For instance, the curving Roc Von restaurant and Bamboo Wing restaurant are the iconic examples of the bamboo-based buildings in Hanoi, Vietnam in which the latter is recognised as a pure bamboo structure without the presence of steel or any other artificial structural resources. Moreover, the Green Village and Bamboo Playhouse are also the representative green buildings in ASEAN countries [50]. Generally, the countries of Vietnam, Indonesia, and Malaysia express positive and increasing trend in involving bamboo as the construction material to promote sustainable construction.

4.2. Recycled concrete aggregate.

The recycled concrete aggregate (RCA) has recently received substantial attention and interest as it helps to reduce the dependency of adding natural aggregate in the cement production and to decrease the waste quantity that generated from the demolition of the buildings. It arises as a new and advanced green material to overcome the overgeneration of the construction and demolition wastes through recycling. For instance, the government of Singapore allows the application of RCA in concrete at low percentages that range from 10% to 20%. Samwoh Eco-Green Building, new three-storeys office building owned by the Samwoh Corporation, a prominent concrete aggregate recycling company in Singapore, is recognised as the first construction project that involved the concrete with 100 % RCA concentration that derived from construction and demolition waste which is ahead of the code restrictions for structural concrete in Southeast Asia. The success of the Samwoh Eco-Green Building represents as an indication of developing towards a sustainable construction [51].

Apart from that, the recycling concrete is also being extensively practiced in Thailand. It is known that Thailand Central Lab has collaborated with Thailand Recycling and Tesaban Nakhon (TN) to study on the valuable construction and demolition wastes for recycling and reusing purposes. TN, as a city municipality, supports a diverse of schemes on promoting green construction project and sustainable building materials. For example, a new crushing plant is implemented in TN as an enhancement to the local construction industry by introducing the technology to transfer the waste material into aggregates to replace or substitute the natural aggregates in the concrete manufacturing [52]. Thus, the local construction firms also promote the green and sustainable construction to maximise the value of the wastes by utilising over two tonnes of RCA to manufacture green concrete [53].

4.3. Coconut husk and bagasse.

Recently, a trend is observed in the construction design which emphasizes on controlling the internal environment to create comfortable conditions without the mechanical air conditioning. Hence, the technique of practising thermal insulation between the walls and roofs is introduced in the construction firms to achieve the goal of reducing the utilisation of air conditioning. The thermal insulation products that available on the market is primarily depending on mineral wool, fibreglass, or polyurethane foams as the raw materials for the production [54]. Despite that the characteristics of good thermal protection, low thermal conductivity and high fire resistance that exhibited by these material, they pose a health threat to both human and environment. For instance, the individual who is exposed to the glass wool or fibreglass can experience skin or respiratory problems at low concentrations. Hence, Thailand has recently emphasised on discovering and studying alternatives such as coconut husk and bagasse as the raw materials in the manufacture of thermal insulation products [55]. Normally, the addition of chemical binders including phenolic resins or formaldehyde is required in the manufacture of thermal insulation products which the added chemicals are considered hazardous and toxic to human health while the manufacturing that involve coconut husk and bagasse can be performed without chemical binders which result in more positive environmental and health impacts [56]. Furthermore, the insulation boards that made up of coconut husk and bagasse exhibit thermal conductivity that range from 0.046 to 0.068 W/mK which show similarities to the conventional insulation materials: mineral wool and cellulose fibres [57]. Hence, bagasse thermal insulation board is widely used in the insulation of roof in Philippines [58].

Table 4. Green Construction Material in ASEAN countries.

Green Construction Material	Location for the implementation	Advantage	Reference
Bamboo	Vietnam, Indonesia Malaysia	– High renewability – High strength – High availability – High workability	[47–49]
Recycled Concrete Aggregate (RCA)	Singapore, Thailand	– Reduce the waste quantity generated from construction and demolition – Reduce the exploitation of the natural resources by substituting natural aggregates in concrete production	[50, 51, 53]
Coconut Husk and Bagasse	Thailand, Philippines	– Reduce the utilisation of mechanical air conditioning – Environmental-friendly – Positive health impacts compared to conventional thermal insulation products	[55–58]

5. Green Materials Technologies

5.1. Hydrogen energy.

Hydrogen is recognised as the amplest element that available in the atmosphere and utilised as the primary resource for electrifying the fields of transportation, industrial, and residential. It is identified as the representative of the clean energy sources regarding on its applications in diverse areas including petrochemical and oil refining industries and ammonia manufacturing. Generally, hydrogen can be classified into three different categories: (a) grey hydrogen, (b) blue hydrogen, and (c) blue hydrogen. Grey hydrogen is referred as the hydrogen that produced from gas and coal which approximately 95% of the hydrogen while blue hydrogen and green hydrogen are referred as the hydrogen that produced from carbon capture, sequestration, and storage (CCS) and from renewable resources which only accounts less than 5% of the total hydrogen production [59]. Green hydrogen is discovered to be the green energy alternative as only water electrolysis is involved in the production of it. The characteristics of hydrogen such as energy-dense, storable, light-weighted, and without direct greenhouse gas emission contribute to its role as the potential secure and clean energy resource in the future. It is capable of greatly contributing to clean energy evolutions by playing important roles in several sectors including energy storage, power generation, buildings construction and transportation. Hydrogen fuel is adept of facilitating the transition to a low carbon energy source at relatively low contribution in the global power consumption which is deemed to be a great potential to mitigate the climate change. Hydrogen can continuously promote an enhancement in the scope of renewable energy at a reduced expenditure of the innovative green technologies. Additionally, the current hydrocarbon-based economy can be transformed smoothy to a hydrogen carbon economy through the combination of the hydrogen and natural gas. It shows that the hydrogen is able to offer flexibility in clean and sustainable energy production in a long-term transition [60]. Generally, ASEAN countries experience high demands in energy and infrastructure are encouraged to adopt the hydrogen economy to move towards renewable-based future.

A decrement of at least 50% in the pricing of hydrogen is predicted by the year of 2040 in the case that hydrogen energy is practised across all the sectors in which it is competitive as the cost of gasoline. Currently, the cost of renewable energy resources is higher than the gas at a factor of five which hydrogen energy is anticipated to reduce the overall cost. Green hydrogen is deemed as an accelerator to shift the global market to a green economy. It is known that Organisation for Economic Cooperation and Development (OECD) countries are planning to implement several hydrogen-based projects which involve the distribution to end-consumers and electrolysers through major pipelines. ASEAN countries are known to be benefited from the development of hydrogen as the accelerator of the clean energy carrier and storage [59]. Hydrogen energy is yet to be included in the policy agenda as alternative resource in most of the ASEAN countries. Nonetheless, it is anticipated that the implementation of hydrogen energy in the policy measures is likely to be recognised and acknowledged as alternative and emerging technology since there is a preparation on including hydrogen and energy storage in ASEAN Plan of Action for Energy Cooperation (APAEC) for the upcoming ASEAN Ministers on Energy symposium to obtain endorsement. It is an opportunity for the ASEAN countries to expand the diversity of renewable energy by promoting the utilisation of hydrogen in power and transportation sectors. For example, Brunei plays a crucial role in the supply chain of hydrogen by offering liquefied hydrogen to Japan ever since 2019. Additionally, other efforts including a hydrogen energy roadmap is implemented by the Sarawak State Government in Malaysia for the year 2005 – 2030 towards a green development [61].

Nevertheless, the hydrogen energy end use technology is yet to be considered as mature as the conventional technology in which immature technology is normally associated with high expenditure and relatively low durability and viability. In addition, the feasibility of hydrogen storage remains a challenging barrier which shows inefficiency in energy storage and utilisation. For instance, pressurization and liquefaction are required for approximately 20% of the hydrogen energy and 30% of that respectively for gas phase storage. Besides, the processes are associated with very low temperature and high pressure which attract public interests on the issues of safety and health. Nonetheless, it is important to continue to perform research on the hydrogen energy as it is capable of providing significant advantages including high flexibility in fuel selection, low or zero greenhouse gas emissions [61].

5.2. Carbon Capture and Storage (CCS).

CCS is an advanced technology that provides a feasible approach to minimise the environmental damage caused by the practise of the fossil fuels through capturing approximately 90% of the carbon dioxide (CO_2) that produced from the fossil-based power generation plant to prevent it from entering the atmosphere. It is known that the production of the clean hydrogen from fossil fuels is achievable through CCS technology that is associated with proper capture and storage of CO_2. Currently, majority of the clean hydrogen production is installed with CCS technology as it is proven to be more cost-effective than the clean hydrogen production that practised with electrolytes and renewable sources [58]. Interestingly, the integration of CCS technology and renewable biomass allows complete capture of CO_2

from the atmosphere that result in carbon-negative [53]. The potential to implement CCS technology in Southeast Asia countries is high due to the presence of various geological storage resources within the region. For instance, the counties such as Thailand, Indonesia, Philippines, and Vietnam with around 54 gigatonnes of the storage capacity show great potential to capture and conceal substantial amount of CO_2. Carbon capture, utilization and storage (CCUS) technology is greatly promoted in Asia since 2009 by the Asian Development Bank (ADB) [57]. Since natural gas power and processing plant are known to be the lowest capital options for CCS technology, recognitions as the best capture sources are attained from ADB. Nevertheless, the development rate of CCS technology varies with different countries. For Singapore, much attention and interest from public and private industries are gained on CCS technology ever since 2017. At the same time, the implementation of legal framework on CCS is considered by Indonesian government for the execution of the large-scaled gas project with great concentration of CO_2. On the other hand, CCS development in power generation, oil and gas industry is prioritised by the Malaysian government through research on the storage assessment and capacity development as well as the preparation of the establishment of the legal legislation [61]. The overall capital cost of installing current CCS technique remains expensive although it is considered as an existing technology [62]. CCS technology involves at least three complicated industrial processes including capture, transport and storage or disposal which a single revenue stream is yet to be implemented to trade the captured CO_2 to the industry of enhanced oil recovery. Furthermore, it is discovered that the current CCS technique experience technological limitations despite the presence of a great variety of commercial-scaled infrastructure in the market. For example, the operation design and equipment for precombustion of the captured carbon experience technical constraints and uncertainties. Thus, corrosion and fouling problems at reformer components that related to carbon deposition are also identified as the technical issues in the CCS procedure. These identified issues might raise concerns on the public acceptance regarding on the safety and health, performance efficiency and environmental impacts of the CCS technology. However, CCS technology is deemed as a promising technology to accomplish green energy system which require continuous research and development to stabilise the technique [63].

5.3. Solar power.

Southeast Asian region exhibits the greatest potential in solar energy due to its unique geographical location. Particularly, substantial amount of solar energy is received by the ASEAN countries throughout the whole year. Hence, the development in the solar photovoltaic (PV) is greatly promoted within the region in which the cumulative solar capacity is accumulated to a total of 22.85 GW. Nonetheless, it is known that the rapid growth on solar PV is considered as uneven among the ASEAN countries. For instance, the main contributors of the solar PV capacity are identified as Thailand followed by Malaysia and Indonesia between the year of 2011 and 2014 [58]. The implementation of solar PV capacity of Philippines surpasses Malaysia and Indonesia by the year of 2016. Interestingly, Vietnam achieve remarkable growth in the solar PV within three years period from 2017 to 2020 in which a total of 17 GW in solar PV development is attained in the year of 2020. Across the recent years, increments in the share of solar energy in energy generation are shown by majority of the ASEAN members. Solar energy is extensively promoted and practised at a global scale due to its characteristics of affordable and cost-effective. It is known that the overall expenditure of solar implementation is greatly reduced in 2009 which is then recognised it as energy efficient approach in energy production [64]. Besides, solar energy-based applications can be utilised or practised without any concern on causing pollutions to environment. The existing pollution mitigation measures are considered adequate and effective to handle the manufacture end-wastes and emissions. However, the collection of solar radiation or energy is highly dependent on weather and daytime only. It is required to implement an energy storage system to ensure continuous and uninterrupted power supply in which the installation of system is an additional cost that raise the overall cost. In addition, the average conversion efficiency of the solar PV panels is yet to exceed 20% which is relatively low compared to other conventional energy conversion system. Hence, more solar panels are required to be installed to achieve higher efficiency to support the energy supply which result in larger space for installation [65].

Table 5. Green Material Technology in ASEAN countries.

Technology	Location for the implementation	Advantage	Disadvantage	Reference
Hydrogen Energy	Brunei, Malaysia	– Energy-dense – Storable – Light-weighted – Without direct greenhouse gas emission – Promote transition to a low carbon energy source – Renewable energy	– Immature technology – High capital cost – Relatively low durability and viability	[50–52]
Carbon Capture and Storage (CCS)	Singapore, Indonesia, Malaysia	– Cost-effective – Allow complete capture of CO_2	– High capital cost – Experience technological limitations	[52–56]
Solar Energy	Thailand, Malaysia, Indonesia Vietnam	– Affordable – Cost-effective – Pollution-free	– Weather dependent – Low average conversion efficiency – Require more solar panels for high efficiency which result in larger required space and high capital cost	[59, 62–65]

6. Conclusion

ASEAN countries are actively working to embrace green and sustainable construction practices by implementing more effective Environmental Management Plans (EMPs), which include policies, regulations, programs, legislation, and other measures. In this context, we will discuss the implemented EMPs in countries such as Malaysia, Vietnam, and Singapore.

The implementation of diverse EMPs aims to foster the development of green and sustainable construction by reducing the overall quantity of waste generated during the construction process. The goal is to minimize the environmental impact and alleviate the pressure on the environment. Among the ASEAN member countries, green materials such as bamboo, Recycled Concrete Aggregate (RCA), coconut husk, and bagasse are being actively used. These environmentally friendly construction materials are recognized for their ability to reduce the environmental impact when compared to conventional building materials. In addition to green materials, various green technologies are being implemented among ASEAN countries.

These technologies include hydrogen energy, Carbon Capture and Storage (CCS), and solar power. The purpose of these green technologies is to decrease pollution and alleviate the current pollution levels. Therefore, collaboration from each country is highly required and appreciated to collectively steer the world towards a greener future.

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Competing Interest

All authors declare no competing interest.

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