Sustainability Indicators Review of Hemp Shiv as Alternative Materials for the Construction Industry in Thailand

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Abstract

Currently hemp is promoted worldwide for its many uses, however, in Thailand it is still limited and in the trial period. All parts of hemp can be utilized; the flowers, leaves and roots are used for medicinal and treatment purposes, food supplement, vitamins, etc. The stalk fibers are used in the fabric industry and are being researched for applications in the energy and other high-tech industries. The leftover stalk or hemp shiv is used as wood replacement or applied in the construction industry in various forms in countries where hemp is grown and used in the industrial scale but in Thailand they are still left as unmanaged or invaluable waste. Hemp shiv possesses characteristics of desirable construction materials in hempcrete and hemp concrete blocks replacing coarse aggregates. There are many researches on its abilities as wall materials showing that they have the potential of being used as non-load baring walls. However, the amount of hemp shiv required to sustain production will require land use change from edible to non-edible economic crop. This is very risky and the result may increase the vulnerability to the effects of Climate Change. Thus, the objective of this study is to assess the sustainability of hemp shiv as alternative materials for the construction industry in Thailand based on sustainability indicators on environment, social and economic impacts of industrial hemp and CO_2 offset for using hemp as coarse aggregates and also to explore the economic feasibility and increased potential for upcycling hemp waste as construction products.

Keywords: Sustainable Construction, Eco-materials, Upcycling, Green Economy, Land Use Change, CO_2 Offset

1. Introduction

Globalization, urbanization, increased population are phenomena that requires supporting facilities and are the main reason for increased construction requirements. According to the Global Status Report 2017 the building and construction sector is responsible for 39% of the energy-related CO_2 emissions [1]. The amount of CO_2 emissions from developing countries' construction activities make up 60% of the global emission from the construction sector with 92% of that being indirect emissions [2]. Like any other industry, the construction industry must change and adapt to the changing demands and to the changes in the availability of raw materials, cost of extraction and global practices. As the Climate Change situation is showing more severe impact on the global scale, the necessity and urgency to move from cement-based conventional construction to more sustainable options is a way to adapt to the situation and mitigate potential problems in the construction industry at the same time.

The use of agricultural wastes and other types of wastes have been considered and are found to be sufficient as partial replacements for aggregates in construction materials. The applications created options for reducing the use of virgin materials and offers improved qualities such as thermal insulation [3, 4, 5]. Thailand's 20 year national strategy gives importance to environmental issues and lowering carbon emissions from all sectors. Existing field crops such as rice, animal feed corn, cassava and pineapple, and plantation crop such as oil palms, coconut trees, rubber trees and durian are all plausible substitutes for aggregate mixtures in construction materials; however, they are already being used as animal feed, natural fertilizers, etc. Hemp is another crop that has potential as alternative for construction materials due to the added properties hemp fibers brings to the mixture. Hemp is known to be used as insulators and wall materials in countries where it is industrialized, however, the recent introduction of hemp in Thailand and the movement to legalize it as another option for economic crop is still a controversial topic. Thus apart from the engineering properties and applications, it is important to consider the sustainability issues involving the application. Hence, this study will review the sustainability aspects of using hemp shiv as alternative materials for the construction industry in Thailand.

2. Sustainability Indicators Review of Hemp Shiv as Alternative Materials for Construction Industry in Thailand

2.1 Sustainability Indicators in Construction

Ever since sustainable development was defined in 1987 in the Brundtland report as, “Development that meets the needs of the present without compromising the needs of the future generations to meet their own needs,” it became one of the basis of consideration for many sectors, especially those involving consumption of natural resources. In 1991, the International Union for Conservation of Nature (IUCN), United Nations Environment Program (UNEP) and World Wildlife Fund (WWF) proposed that sustainable development is the improvement in the quality of life for humans while accounting for the carrying capacity of the ecosystem. More recently, the quality of life of people in terms of communities and sustainable cities is recognized globally under the United Nations’ Sustainable Development Goals 9 and 11 and nationally under the National Economic and Social Development Plan No. 12 and was applied into Thailand’s 20 years Master Plan for National Development. Consideration of sustainability in the construction sector also covers all the three pillars including social, economic and environment pillars.

Huang et al. [2] studied the carbon emission of the global construction sector using the world input-output database developed by the 7th Framework Programme of the European Commission and found that in 2009, the total global CO_2 emission from the construction sector is 23% based on global economic activities. Comparison of direct and indirect energy consumption found that indirect activities such as resource extraction use significantly more energy than direct construction activities. The production of cement makes up 14% of the non-energy consuming CO_2 emission from indirect construction activity.

Rault, Ralegaonkar, and Mandavgane [4] reviewed options for selected industrial and agricultural wastes in developing countries such paper processing residues, cigarette butts, fly ash, textile effluent treatment plat (ETP) sludge, polystyrene foam, plastic fiber, straw, polystyrene fabric, cotton waste, dried sludge from industrial waste water treatment plant, rice husk ash, granulated blast furnace slag, rubber, kraft pulp production residue, limestone dust and wood sawdust, etc. were used at different percentages in brick making in order to explore its application into construction material. It was found that using waste as substitute materials produced light-weight bricks which are good for transportation management. Results of the study indicated that a combination of waste material can be used with paper pulp and paper processing residue to product waste-create bricks that are environmentally sound, economical friendly and passes engineering requirement for application. Paper pulp and paper processing residue on its own have approximately 12 times higher comprehensive value than required by IS 107-1992 however, its water absorption is also much higher. Enhanced performance of waste-create bricks should also be considered along with the physic-mechanical and chemical properties of bricks. The density, thermal conductivity and comprehensive strength are basic requirements whereas economic viability is an indicator that should be considered for green material.

According to Yilmaz and Bakiş [5], environmental sustainability must take into consideration the carrying capacity of the environment and ecosystem, the time it takes for resources to revive itself, contamination and effects from harvesting resources and the trade-offs that comes with it, and how to minimize the effects of human activities on the environment. Economic sustainability is ideally the power to produce and buy goods without limitations. However, with consideration of resources availability, economic sustainability cannot be sustained if resources are depleted and recovery cycle is not sufficient to provide for production and consumption. Social sustainability is such that the future generations have access to resources that can sustain their livelihoods. The activities in the construction sector consume a lot of resources and energy and also produce a lot of pollution creating negative impacts on the environment and society. An approach that will help create sustainability in the construction sector is to adapt the design and concept of building and infrastructures so that they are more concerned for the natural resources and environment as well as the life cycle of the materials and the finished building/facility. Applying the life cycle concept to construction will increase sustainability in the construction sector from the planning stage and throughout its work cycle, including material selection and waste management. Other than that, land use change is a major concerned and proper planning is required. Specific properties of materials such as low embedded-energy materials and low impact virgin material process are also part of the indications for sustainability in construction. One hold-back is that the demand for eco-materials is still low due to the price of products and mind-set of consumers.

Colangelo and, Forcina et al [6] explored the sustainability of waste-mixed concrete based materials by applying the ISO14040 standard. The life-cycle inventory was used to determine and compare the energy consumption between virgin material extraction and raw aggregates production. The input materials included Portland cement, water, natural aggregates and recycled aggregates together with fuel, energy and water during transportation and production were considered to determine the resultant GHG and land emissions. Results showed that using recycled aggregates will contribute to lowering Global Warming (GW) and the improvement of environment problems from the construction sector.

Panyakaew and Fotios [7] studied the application of agro-waste as thermal insulator in construction materials for residential buildings to address the issue of availability of natural resources for construction materials which is limited to the construction industry and thus a threat to the sustainability of the industry. Agro-industrial and other solid wastes are options for raw materials for construction materials that solve the problem of resource limitations for the construction industry and also the waste management problem for industrial and solid wastes. Agro-wastes can be used to produce variety of construction materials such as particle boards, thermal insulators, masonry composites/bricks, cementitious/ pozzolana/binder materials, used as aggregates, fiber reinforcement, and reinforcement materials. The proportion of each type of waste into the material varies depending on the required engineering properties for the products and its applications. Mechanical properties tested for rice husk, bark, and ash at 10, 20 and 30% and a w/c ration of 0.28% resulted in compressive strength at 28 days of 86, 88 and 85 MPa for the designed strength of 78 MPa. For palm oil at the same cement replacement and water ration percentages resulted in comprehensive strength at 28 days of 81, 86 and 80 MPa. It was found that the fiber reinforced cement is becoming popular because it also offers lightweight option as well as good thermal-acoustic properties and has economic viability.

Gan, Zou, Ye, Skitmore and Xiong [8] took another approach in looking at the sustainability of the construction sector. It is important that there is a demand in the market for the eco-materials otherwise it will not make sense economically to produce the materials even though the construction market is increasing rapidly due to urbanization. There must be supporting policy as well as economic viability and consciousness of end users. Sustainability in construction does not always require high technology, however, the confidence of the users may require advanced technology in the production process which causes problems for developing countries. Another obstacle is the availability of standards and codes for the materials which will be a limitation for the material to enter the market. A survey questionnaire was designed and performed to find out the preferences of the end users and 25 critical factors which influence owners to choose sustainable construction materials were identified. Results of the survey found that economic feasibility is the most critical factor influencing the application of sustainable construction methods and materials.

Ferrer, Thomé and Scavarda [9] reviewed the concept of sustainable urban infrastructure and concluded that the concept is multi-leveled and is interlinked between climate-change issues, economic growth, urban growth, environmental costs, resources availability, decisions and supporting systems and urban infrastructure system. The concept itself has evolved through the years with the evolution and growth of society as well as advances in city infrastructure. The most recent criteria for sustainable urban infrastructure involves disaster mitigation, having a low maintenance but highly efficient city system, being a resilient city and providing livable conditions adaptable to the induced changes of climate change situation.

Karakoç [10] studied alternative materials or designed housing to be marketable and accepted by consumers it must first be supported by government mechanisms such as policies or regulations. Therefore, the criteria for materials used in green housing, eco-friendly houses, energy efficient homes, etc. are important for practical applications. At the present, there are standards for alternative materials issued by the International Standardization Organization (ISO) such as the sustainable building construction under ISO 14040, construction materials under ISO 21930 and consideration criteria under ISO 21931. Some tools developed for the assessment of the efficiency in environmental performance in the construction practices such as ATHENA Impact Estimator for Buildings & Eco Calculator and Building for Environmental and Economic Sustainability (BEES) software. The study identified sustainability in the construction sector into 4 main pillars, environmental performance of the material, building performance of the material, economic performance of the material and material characteristics.

Khasreen, M.M., Banfill, P.F.G., and Menzies, G.F. [11] reviewed the life cycle assessment (LCA) tool and recommends it for use to determine the environmental impact of buildings in detail. LCA will be able to identify the impacts at every stage of the construction and throughout its life span and can work with multilevel datasets.

Liew [12] presented that the commonly used wastes in construction practices are from 3 sectors, agriculture (rice husk ash, corn cob ash and sawdust ash), industrial (fly ash, silica fume and granulated blast furnace slag) and municipal wastes (glass, plastic and paper). Biocomposites construction products are being studied in a wide range as they are based on renewable resources but there are some complexities and challenges in terms of engineering properties for the materials in terms of applications. A mixture of agricultural waste is also a possibility to achieve required strength for the product [13].

Krizmane, M., et al. [13] explored the key criteria for existing sustainable building rating tools and suggested that applications should be consistent with local regulations, certification systems should be applied and tools such as LEED and BREEAM certification systems can be used for measuring energy efficiency. This can be used for determining the sustainability of the building performance after the construction phase. However, although existing tools can provide confidence for quality according to the sustainability principles, policy framework, legislation and market support is still required for end users or owners to decide to apply sustainable design for buildings and utilize sustainable construction materials so that they can be marketed.

Nielsen [14] used the life cycle tool to assess Carbon footprint of concrete buildings based on the Danish cement and concrete industry case study. It was concluded that during the production phases the carbon footprint of concrete is higher compared to light-weight materials. Alternative materials for cementitious materials will greatly reduce the carbon footprint of concrete because most of the emissions are in that process. When concrete building becomes of age it should be torn down and the material should be reused in other applications that are safe in order to offset the CO_2 created. The differences between concrete structures and light-weight structure in terms of CO_2 footprint can be anywhere from 10 to 50 years.

Danso, H. [15] reviewed studies on properties of sustainable construction materials which are commonly used and identified the 25 indicators for sustainable construction materials based on the three pillars of sustainability. Of these indicators, 12 was suggested for use as the baseline for future studies exploring the sustainability of construction materials including 3 indicators for environmental sustainability, 4 indicators for social sustainability and 5 indicators for economic sustainability. The environmental sustainability indicators include human toxicity, climate change and solid waste. Social indicators include adaptability, thermal comfort, local resources and housing for all. Economic sustainability includes maintenance cost, operation cost, initial cost, long-term savings, and life span of the material.

2.2 Potential of Hemp Shiv as Alternative Construction Material

Pantawee, Sinsiri, Jaturapitakkul, and Chindaprasirt [16] studied the potential of hemp shiv for use as coarse aggregates in concrete based material. It was found that hemp concrete of 1420-1470 kg/m^3 density aged 28 days had the comprehensive strength of 15.0-17.0 MPa and water absorption content of 14.5-16.5% for $Al_2(SO_4)_3$ treated hemp shiv. This was one of the earlier studies on the application of hemp in construction materials in Thailand. The study on the physical and mechanical properties of hemp concrete resulted in satisfactory basic block material indicating that hemp can be used to replace coarse aggregates in the concrete-based material [16].

Arrigoni, A., et al. [17] performed life cycle assessment of natural building materials looking at the role of carbonation, mixture components and transport in the environmental impacts of hempcrete blocks. The study showed that the use of hempcrete is growing quickly across Europe and North America because they can use build on site techniques and this lowers the emissions from transport in its life cycle. Hempcrete blocks stores high amount of carbon and as building materials they will be removing more carbon than they emitted during the growth and block production process. CO2 is also absorbed during carbonation process which takes up to 240 days. It is suggested that consideration of indirect land use change should be considered as part of the environmental impact assessment if hemp will be grown on the industrial scale to support the construction industry. This may limit the biomass stock required and thus limit the market for hempcrete or other hemp-based construction materials.

Florentin, Y., et al. [18] suggests that using hemp-lime bio-composite building materials has advantages over other materials because of the unique properties of hemp in carbon sequestering. Hemp-lime composites may be further developed into load baring construction materials. The bio-fibers are applicable for use in construction requirements and are potential alternative as efficient mitigation option for construction materials. Furthermore, hemp-lime material may contribute to long-term reduction of energy requirement in buildings.

Dhakal, U., et al.[19] studied a bio-aggregate based composite material, hempcrete, and found that the material has low thermal conductivity (0.074 to 0.103 W/mK) and it is an effective moisture buffer. Hempcrete materials can absorb noise better than pure concrete materials and also has high carbon sequestration index. Hemp is good quality bio-light-weight aggregate, however, it will also make the blocks have lower comprehensive strength as it has higher porosity. At the same time, marketing of hempcrete is limited to the niche market.

Elfordy, S., et al. [20] found that the flexural strength of hemp and lime ranges from 0.832-1.191 MPa for mixture density of 430-607 kg/m^3.. This is relatively low compared to other materials. It should also be noted that the higher the density the lower the thermal resistance.

Wahyuni, A.S. et al [21] tested the performance of rice husk ash, sea shell ash and bamboo fiber as additives to concrete mixture. Test results show that the tensile strength is increased with the addition of all 3 materials with bamboo fiber reinforced concrete as the most comparable to that of normal concrete.

Pittau et al. [22] performed a study focusing on the application of bio-based materials in wall structure applications and in addition to that studied the CO_2 emission reduction potential using life cycle inventory (LCI), life cycle assement (LCA) and dynamic life cycle assement (DLCA) to identify GWI and GWP. Results showed that the material's performance in the walls were good, with the addition of walls with straw and hempcrete and hemp shiv showing negative Global Warming Index (GWI). However, the study suggested that further studies should be performed for the magnitude of impact on climate change if large scale plantations are encourage to secure supply of bio-composites even though they are good alternatives for cementitious materials.

Çomak, B., et al. [23] found that the comprehensive strength of cement motar is improved with 2-3% of added hemp fiber and they have good adherence to cement. The suggested fiber length is 12 mm for best results as reinforcement materials. The sample mixtures have densities of 2065 kg/m^3 and 2156 kg/m^3.

Shahzad [24] concluded that as hemp fibers are being used as reinforcement materials more and more they still have their weakness in water absorption. Application of hemp fiber to replace synthetic fibers will require enhancement of fiber properties. However, the tensile properties of hemp fibers are sufficient for use in composite materials as substitution for glass fiber in general.

Ingraol, C. et al. [25] concluded that the production cost of hemp-based construction material will be higher than conventional raw materials. However, its quality and properties are competitive in the growing eco-market and green economy trend. In this regards, enabling policies such as the EU's policy to support producers of hemp-based materials should be considered to encourage the application of hemp in the production of construction material market and industry.

3. Discussion

The reviewed literatures suggest that hemp shiv have positive potential as eco-materials in the sense that they make energy efficient construction materials, are renewable resources, and have CO2 offset potential both during supply production and as a finished product. These traits contribute to the sustainability of construction sector. However, for Thailand, sustainability criteria for promoting industrial hemp that should be considered should include land use change from food production land to industrial hemp land as suggested by [5-6], [15], [22]. The 12 baseline sustainability indicators for sustainable construction materials suggested by [15] are relevant but should also be customized for more details for hemp. Upcycling hemp shiv is an option to create green economy but the market demands and the economic viability must be considered [5], [8], [19]. This is because hemp production in Thailand is not industrialized and in order to sustain the production of construction materials using hemp on the industrial scale the environmental, economic and social requirements will need to be prioritized in details.

Studies reviewed show that preliminary properties of hemp applications in construction materials are consistent with the growing need for green construction. It has the potential and will contribute to lowering the carbon footprint of construction material production and building at the end of use. Moreover, if hemp is produced on the industrial scale, the use of shiv in construction materials will be a way to upcycle the waste material from the industry and support the circular economy and green economy concepts which are consistent to Thailand's development strategy. Further studies will be required to identify the appropriate mixture for construction material using hemp and other agro-waste. However, some materials such as rice husk or corn cob studied [4, 21] may not be good options for Thailand because they are already being used in other industries. More precise details on economic efficiency should be explored to verify the cost-effectiveness of the investment.

Hemp shiv as waste materials from the industry on its own are carbon-negative and the hemp-added eco-material products can account for CO_2 offset in the other parts of the building construction lowering the overall CO_2 emission of a building [6], [11]. Existing sustainability assessment tools such as ISO 14040, ISO 21930, ISO 21931, LEED and Building for Environmental and Economic Sustainability (BEES) [10], [13] should be applied with projected information for hemp production in Thailand.

It should be noted that production of basic hempcrete and hemp concrete or even in-place construction using hemp-lime mixture doesn't require high technology or applications. However, for mass production more advanced technology should be adopted and apply to ensure long term economic efficiency for the production process. Also, to ensure market access of hemp construction products in Thailand, a survey assessing end-user requirements and acceptance level should be performed. The mindset of the end-users in developing countries like Thailand may not be willing to pay much more for eco-materials than what they are paying for conventional materials even though they are aware of the climate change problem and environmental issues. The survey may include questions that will help collect information which will be useful for future design and development of construction products from hemp. In addition to the GWP and CO2 offset potential [17], [22], other benefits of hemp composite materials such as thermal conductivity [19], improved physical and mechanical properties [16], [18-12], and [23] should also be considered. International market such as Europe and North America where there are demands for hempcrete [17] may be an alternative option for market access, however the transportation process cost and CO_2 footprint will increase drastically so the trade-off and eco-efficiency should also be considered. The information can then be used to support decision making process in more detail.

The local details of each indicator should be further identified and explore. Using hemp shiv in its basic form may be a low technology production method but it offers physically and mechanically usable lightweight eco-material product. More advanced applications such as hemp fibers in other forms for reinforcement materials are also an option and further studies are encouraged. Non-cementitious based materials such as hemp-lime composites or hempcrete [18-19] are products that have potential as eco-materials for construction but improvements are required in terms of strength and design to enhance its applications in construction and make them more marketable.

Another concern on industrializing hemp production which is a major sustainability criteria is land use change which may impact food security and create social conflict. Enabling legal frameworks for implementation and applications should be discussed and knowledge and information should be disseminated to stakeholders, specifically farmers so they can make informed decisions before they alter their food crop land to hemp production fields.

From the above discussion and considerations, the sustainability indicators for hemp shiv applications as eco-materials in construction based on suggested indicators by [15] that should be highlighted are suggested as follows.

Environmental indicators: human toxicity, climate change, solid waste and land use change.

Economic indicators: market access, supply, maintenance cost, production cost, initial cost, long-term savings, and life span of the material.

Social indicators: adaptability, thermal comfort, local resources, food security.

4. Conclusions

In conclusion, the reviewed literatures showed positive potential for using hemp shiv to produce eco-materials for construction in Thailand. It has the potential to support the green economy concept in terms of being eco-material and contributing to lowering carbon emissions from the construction industry as a substitute to cementitous material by off-setting the CO_2 emission for the cement production process with the carbon negative hempcrete production. On the economic front, upcycling of hemp into construction material requires studies on cost of production and selling price. This can be performed in parallel with the LCA process and interpreted the collected LCI data. On the social front, food security from land use change may become an issue at the industrial scale and careful consideration and land use planning may help to solve and manage this problem. A more holistic approach may be applied to reduce conflicts and create understanding with local applications. Furthermore, for the sustainability of green construction materials hemp-based bio-composites should also be considered rather than relying only on using hemp shiv. For such materials, physio-mechanical and other engineering properties testing will be required to ensure compatibility and safety of application of the product in the construction industry. Meanwhile, the sustainability indicators should be used to carry out subsequent studies for future promotion of application of hemp shiv in the construction material production for Thailand's construction industry.

5. Further work

Further work will include identifying sustainability indicators for industrial hemp production in Thailand based on the sustainability indicators review using qualitative survey. This will be followed by a quantitative study on CO_2 emissions related to hempcrete in Thailand will be carried out using LCA methodologies together with other sustainability assessment tools such as ISO 14040, ISO 21930 and ISO 21931 based on the sustainability indicators identified. In parallel to that, the results of the application of hempcrete as wall materials in terms of energy efficiency, thermal conductivity and indoor air quality will be assessed.

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