From Field to Circular Economy: Evaluating Kenaf's Potential Through Environmental Economics and Design

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Abstract. Circularity collaboration between economics and design is crucial to work together towards a common goal of sustainability through the exploration of renewable resources such as kenaf (*Hibiscus cannabinus*), a fast-growing and versatile plant that has great potential as a sustainable raw material. However, the full potential of kenaf has not yet been fully explored, especially in terms of its economic and environmental benefits, as well as its application in circular design principles. Hence, the study aims to demonstrate the availability, technological processing, and socioeconomic implications of kenaf. Although numerous research has been undertaken on this plant, it is vital to revisit its potential from various viewpoints to maximize its application. This paper evaluates the role of kenaf from its early cycle into the production process in promoting its potential for environmental economics by considering circular design principles. By analyzing case studies and current market applications, the methodology used in this study involves reviewing the previous study and text documentation that provides insights into the potential of kenaf usage. The findings suggest that kenaf, when utilized effectively, can significantly contribute to resource efficiency, waste reduction, and overall environmental sustainability, positioning it as a key component in the shift towards a circular economic and circular design framework. Exploration of kenaf potential in this study not only focuses on recycling, reuse, and regeneration but also proposes a redevelopment approach for its underdeveloped materials requires collaboration between economic and design principles. Interdisciplinary studies through these field combinations can develop an efficient, productive, and sustainable economic system that would expedite the shift toward a circular economy and support the development of sustainability goals.

1 Introduction

Kenaf (*Hibiscus cannabinus*) known for its high biomass yield and versatility plays a key role in the effort of integration of environmental economics and design that emerges as a powerful driver towards the urgent need for sustainable development. This valuable renewable resource significantly contributes to the crucial of this interdisciplinary approach in designating solutions that highlight environmental degradation while supporting economic viability and social well-being. Its durable fibers and biodegradable qualities can greatly enhance the circular economy, which explores reducing waste and improving resource efficiency.

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Paper production, bioplastics, textiles, and building materials are various industries that kenaf's diverse potential to span by providing sustainable alternatives to conventional resource-intensive processes. Cultivating kenaf requires fewer agricultural inputs and improves soil health results lowering both production costs and environmental impact that contribute to the environmental economic standpoints. Concurrently, the development of eco-friendly products that boost consumer interest in sustainable options can be achieved through innovative design approaches. This paper seeks to identify a pathway toward a more sustainable and circular economy, highlighting the significant benefits of interdisciplinary participation in achieving global sustainable objectives by evaluating kenaf's prospective through the lenses of environmental economics and design.

2 Literature Review

2.1 Kenaf

Roseberg (1996) [1] overviewed that kenaf was used as early as 4000 BC while *Seller and Reichert (1999)* [2] state that there are over 120 names that are similar to the word "kenaf," including "mesta" in Bengal, "palungi" in Madras, "deccan hemp" in Bombay, "bimli jute" in Andhra Pradesh, "ambali" in Taiwan, "till," "teel" or "teal" in Egypt and Northern Africa, "Java Jute" in Indonesia, "papoula de Sao Francisco" in Brazil, "stokroos" in South Africa, and "dah, gambo and rama" in West Africa. Currently, there is no proof in the literature as to who the kenaf founder is, according to earlier studies. It is believed from the regions, kenaf spread to Asia such as China, Indonesia, Myanmar, Malaysia, and Thailand by sea as now they are traditional growers including United State of America. Africa and Western Africa natives widely used kenaf as a source of food and fibre probably long ago. Kenaf takes two weeks until four weeks to mature and can grow up to a height of eight to twenty feet. The kenaf fibre is used to produce mostly textiles, gunny sacks, and to a certain extent, paper. Recently, new uses for kenaf have been developed for different industrial applications. Products range from biocomposites, paper, textiles, cattle feed, absorbing agents, automotive, Boeing, and furniture. Kenaf is more commonly called "the future crop" [3].

In early 1998, the previous Prime Minister of Malaysia Tun Dr Mahathir bin Mohamad suggests kenaf as the source of food, building construction, and oxygen trading. The first research and development (R&D) in kenaf was conducted by the Malaysian Agricultural Research and Development Institute (MARDI), a government organization in Malaysia to investigate the potential of agriculture. Kenaf is one of the agricultural products identified by the government to be developed as a new growth source in Malaysia. The planting of Kenaf is being implemented in Pahang, Kelantan, Terengganu, Perak, Johor, and Melaka as mentioned by the Ministry of Plantation and Commodity (MPIC 2013). Universiti Putra Malaysia (UPM) was the first public university to take action on R&D in industries application in 1999 followed by Universiti Sains Malaysia (USM) and Universiti Teknologi Malaysia (UTM). They are, enhancing the productivity and production of kenaf, improving research, development, and commercialization, encouraging the commercial production of kenaf, increasing the development of on-stream industries, promoting the use of kenaf and kenaf products, as well as the development of human capital. The move is part of the government's efforts to transform the country into a global commodities hub. In April 2010, the MPIC stood as a government organization in line with the National Commodities Policy (NCP), the National Kenaf and Tobacco Board (LKTN) will work to enhance the development of the downstream industry and promote the production of kenaf products worldwide.

2.1.1. Circular Economy

There are wide varieties of contrivance to society that have been the root of growth well circular economy (CE) that defined as an economic system targeting zero waste and planetary boundaries for sourcing. Under the circular design approach, efforts are made to find a solution for a product or service that is functional and made from optimal materials so that it performs as well as possible, with

the least negative consequences over its full lifecycle [4]. The framework of CE looks to create a circular model in which resources are reused, remanufactured, and selectively recycled for new inputs, instead of requiring large volumes of raw materials that begin their lifecycle with massive ecological footprints. This represents the most change in resource management, focusing on sustainability and waste reduction, and accomplishment of sustainable development by maximizing material utility over product life cycles. This could be achieved by creating environmental quality, economic prosperity, and social equity to secure benefits for current and future generations [5]. These loops of reuse, repair, remanufacture, refurbishment or recycling extend the product life cycle and improve resource productivity [4].

2.1.2. Environmental Economic

Environmental Economics (EE) is an area that focuses on the financial implications of environmental policy, the costs, the advantages and disadvantages of ecological preservation and deterioration. Besides, it involves effective management in the use of natural resources. EE can also be understood as the impact of economic activities and the implementation of policies towards environmental issues. Meanwhile, the challenges of environmental issues may have to be overcome through economic incentives and regulations. These combinations of incentives and regulations aim to change economic behavior in a sustainable direction, by encouraging environmentally friendly practices and complying with certain standards to protect the environment. In Kenaf productions, the methods of Life Cycle Assessment (LCA) and Life Cycle Cost (LCC) have been used to evaluate the impact on the environmental and economic impact of the processing and cultivation stages [6]. For example, the treatment stage in Kenaf production shows the highest negative impact that can affect resource uses, human health, and ecosystem quality [6]. However, besides the flaws, Kenaf-based products also contribute to the high-value and eco-friendly products by integrating bioactive peptides from the human hemoglobin hydrolysate into the Kenaf-based products. The bioactive peptide is a small protein fragment that can lower the oxidation rate and be able to fight the bacteria, inhibit the growth of microorganisms, and extend product life which respectively enhance the antimicrobial and antioxidant properties [7]. This synergy encourages sustainable agricultural use and creates new economic prospects in the food and pharmaceutical industries which aligns with environmental economic aims. Moreover, Kenaf offers the potential of sustainable raw materials for fiber-based industries, particularly in tropical and subtropical climates [7,8]. Therefore, Kenaf keeps gaining popularity in green composite due to its renewable nature, eco-friendliness, and low production cost, making it economically viable [8, 9].

2.1.3 Environmental Design

Creating physical environments that are practical, sustainable, and aesthetically amusing with consideration of the impact and relationship with the natural environment is known as Environmental Design (ED) that incorporates principles from multidisciplinary studies. The aim of ED focuses on enhancing the quality of life and lessening environmental impacts through productive resources, ecological sensitivity, and sustainable approaches. This could be seen through the utilization of versatile plants with numerous benefits of kenaf that shown significant prospective in various practices like in the environmental design of Gamma Valero Lactone (GVL), a bio-based solvent with promising results in lowering global warming potential compared to the conventional production methods [10]. Other than that, [11] highlight kenaf fiber's potential as an alternative material like a substitute for timber and other industrial implementations due to their environmental benefits. Another utilization has been discussed through a paper review of the kenaf composite potential in medical design products of [12], spot on the potential of kenaf composite for fabricating an Ankle-Foot Orthosis (AFO) due to its tensile strength to propylene, and the cheap raw material compared to other types of materials. In automotive design components, the exploration of kenaf fiber potential through the substitute of glass fiber-reinforced thermoplastics that strengthen the desired mechanical properties of automotive structural parts [13]. The crochet exploration of kenaf fibers in textile and fashion

design can produce good strong, volumetric, varied textile materials and fashion accessories [14]. These developments highlight kenaf's growing importance in sustainable product design and manufacturing across various industries.

3 Methodology

This paper has obtained secondary data through a comprehensive review of periodicals on the research topic, namely 'kenaf'. All the reviewed documents have been summarized according to the details of the life cycle of Kenaf, the descriptions, and its relationship with Circular Economy (CE), Environmental Economics (EE), and Environmental Designs (ED). The data collection for the documents is the docile container of knowledge or the initial step to deepen the research subject [15] Therefore, using digital research or the internet as a tool to collect information becomes a place that allows searching with the concept of field site culture [16]. The web database used for this research is 'Google Scholar'. Google Scholar is a 'free-to-use tool' for obtaining academic articles and is recommended for finding research-related research documents specifically [17]. Hence, the search strategy outlined in the flowchart as shown in Figure 1 adopted by *moher et. al.,* (2009) [18]. In the first stage of identification, the search field articles were identified based on their title, abstract, or keywords with a thematic focus on 'Kenaf Potential'. This included a wide range of literature sources such as articles, proceedings, and book chapters. Out of the initial 1,125 identified records, 713 were excluded during the first-round screening. Articles then were reviewed based on their title and abstract to check for relevance in terms of literature focusing on kenaf's potential in areas like the CE, EE, and ED. A further 351 articles were excluded during this step. A more in-depth screening was done by skimming the main body of the remaining articles. The focus was on those that thoroughly addressed the topics. Another 33 articles were excluded. Finally, the records that passed all levels of screening were included in the final analysis for kenaf's potential. To see the review of the Kenaf potentials along with the Kenaf life cycle, it has been discussed according to the previous studies and has listed the description and its potential in the perspective of CE, EE, and ED as mentioned in the findings of this paper.

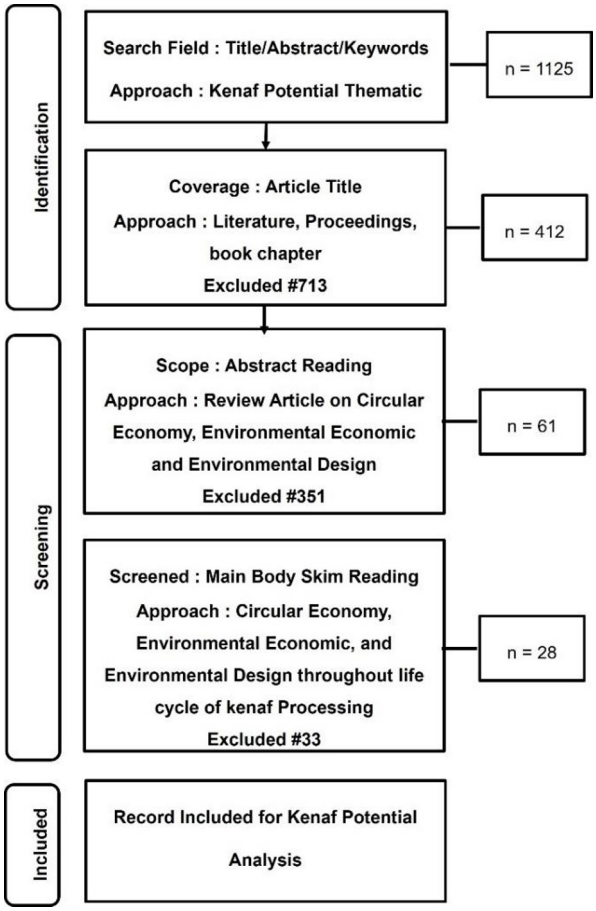

Fig. 1 Flow diagram of the search strategy adopted by Moher et al., (2009) [18].

4 Findings

Reviewing the life cycle of kenaf process and utilization properties and uses of kenaf as potential resources toward environmental, social, and economy. Kenaf has significant potential for advancing circular economy, environmental economy, and environmental design. Below are the potential of Kenaf and the perspective as aforementioned.

Table 1. The Potential of Kenaf in the perspective of Circular Economy, Environmental Economics, and Environmental Design throughout the life cycle of kenaf processing.

Life Cycle of Kenaf	Description	Circular Economy	Environmental Economics	Environmental Design	Sources
Seed Selection	Seeds produced from the kenaf plant are about 6 mm long, and 4 mm in width.	Waste minimization, resources efficiency, and energy production.	Kenaf seed oil can be processed into biodiesel, a renewable energy source that helps reduce greenhouse gas emissions. Kenaf plants are also effective in	Oil extracted from kenaf seeds is rich in essential fatty acids, making it suitable for food, cosmetics, and pharmaceuticals.	[19], [20]

Life Cycle of Kenaf	Description	Circular Economy	Environmental Economics	Environmental Design	Sources
			phytoremediation, removing contaminants from soil and water.		
Flower	Kenaf flowers have 5 petals that are typically similar to other members of the hibiscus family. With color . creamy white, yellow, or pink with a dark purple or red center.	Biodiversity and ecosystem as a self-fertile generally self-pollinated support and habitat provision.	Kenaf flowers can produce natural dyes for textiles and food.	Can be Herbal teas, cosmetics.	[21], [22]
Leave	Leave kenaf have three or seven lobes, with lights 10-15 cm and dark green color.	Agriculture benefits through soil improvement and nutrition value	A good animal feed, especially for ruminants.	Can be utilized in the nutraceutical and pharmaceutical industries.	[19]
Stalk	The stalk of the kenaf plant is tall, erect, and robust, often reaching heights of up to 4.5 meters (15 feet). It is cylindrical and can become quite thick.	Fiber production. Bast fiber and core. Particleboard and fiber base	In the automotive and construction industries application uses.	Can produce durable ropes, twines, and fabrics.	[9], [23]
Stem Core Bast	The kenaf stem consists of two main parts: the outer bark (bast fibers) and the inner core.	Bast fiber, particleboard, and fiberboard	Waste Reduction of material.	Kenaf Fibers have high potential as alternative materials like timber in industrial applications: medical,	[11], [12], [14]

Life Cycle of Kenaf	Description	Circular Economy	Environmental Economics	Environmental Design	Sources
				automotive, textile fashion.	
Planting	It refers to an act of placing seeds or young plants into soil to grow.		Its cultivation requires fewer pesticides and fertilizers compared to traditional timber, resulting in a lower environmental impact.		[24]
Germination and Earthy Growth	Germination is the process where a kenaf seed sprouts and begins to grow, while earthy growth refers to the subsequent development and maturation of the plant in the soil.		Kenaf has phytoremediation properties, meaning it can help clean contaminated soils by absorbing heavy metals and other pollutants. This characteristic makes it valuable for environmental remediation efforts		[25]
Flowering and Maturity	Flowering is the stage of Kenaf plant develops reproductive blooms. Maturity is when the plant is fully formed, it is completely grown, prepared to yield seeds, and ready to be harvested.				
Harvesting	The harvest methods has consistently been hand-harvested			For the use as a cordage crop (rope, twine, and sackcloth)	[21]

Life Cycle of Kenaf	Description	Circular Economy	Environmental Economics	Environmental Design	Sources
Processing	Processing of kenaf involves converting the harvested plant into usable products by separating, cleaning, and refining the fibers for applications like textiles, paper, or composites.		Inexpensive to cultivate and process, which can lead to cost savings in the production	Kenaf can be processed into various forms, such as fibers, particleboards, and composites, allowing for a wide range of design possibilities.	[27], [28]
Utilization	Utilization of kenaf involves using the processed fibers and plant parts to create various products and applications, such as textiles, paper, and building materials.	Kenaf fibers are increasingly being used in the production of biocomposite, which serve as sustainable alternatives to traditional synthetic materials. It is significantly reducing reliance on petroleum-based products : Paper and pulp industry helps mitigate deforestation and reduces the environmental impact of traditional paper manufacturing processes		Kenaf composites can be both strong and easy to handle.	[28], [29]

Life Cycle of Kenaf	Description	Circular Economy	Environmental Economics	Environmental Design	Sources
Waste Management and Recycling	Waste management and recycling in kenaf involve handling by-products and repurposing them into new materials.	: Kenaf are biodegradable , contributing to the reduction of waste and environmental pollution. At the end of their life cycle : Reduction of waste and the continual use of resources			[23]
Replanting	After the harvest, the cycle begins again with the next planting season..				

5 Discussion

a. Key Component of the Circular Economy in Kenaf Application

The significant component of the circular economy in Kenaf is highlighting sustainable materials. Kenaf applications particularly can be applied in areas such as fiber-based industries, green composite, and agriculture. It also refers to its potential in industries that prioritize environmental impact reduction, recyclability, and reusability. Therefore, the key component of the CE in the Kenaf application focuses on waste reduction, recycling, reuse, life extension, redevelopment, and innovation in Kenaf-based products. The goal is fostering a circular system is highly important because the material's use can be prolonged and minimize environmental footprint.

b. Kenaf and Its Challenges

Kenaf presents a significant potential for contributing to the CE. Holistically Kenaf offers eco-friendly alternatives to synthetic materials. Based on Figure 2, the framework represent on how Kenaf relates with the EC, ED, and EE contribution to the sustainable development pillars of environmental, economics, and social value creation. Therefore, the framework illustrated in Figure 2 shows the framework of the Relationship of Circular Economy in Kenaf Application, which also can explain the challenges regarding the Kenaf. Firstly, the discussion towards the challenges is, that there is a lack of research and data reported and published related to Kenaf. The comprehensive research on the lifecycle, economic resilience, and environmental impacts of Kenaf across the various applications are not fully covered as highlighted by [19]. Secondly is the scarcity standardization process in exploring the Kenaf materials. [26] emphasized that the absence of standardized processing may lead to inconsistent product quality and undermine market acceptance. The third challenge is the lack of sufficient market incentives and inadequate supportive policy. Economic incentives such as subsidies

for the farmers who grow Kenaf, and tax deductions for the companies that use Kenaf, can encourage them to switch from synthetic material to environmentally friendly materials. Besides, government support with the marketing, promotion and necessary technology and infrastructure for the Kenaf-based products can alleviate the life cycle of Kenaf with meticulous Research and Development [19]. Thus, these difficulties may make the stakeholders less interested in learning more about Kenaf if they do not consistently receive significant assistance. This will leave the cultivation of Kenaf stay unclear and unconvincing to the stakeholders. The Final challenge that can be pointed out is less of consumer awareness regarding the Kenaf-based products. The understanding of Kenaf benefits and its implications is still in the early stages among the public and potential stakeholders. Not to mention the knowledge is limited to research and development and is looping and repeated.

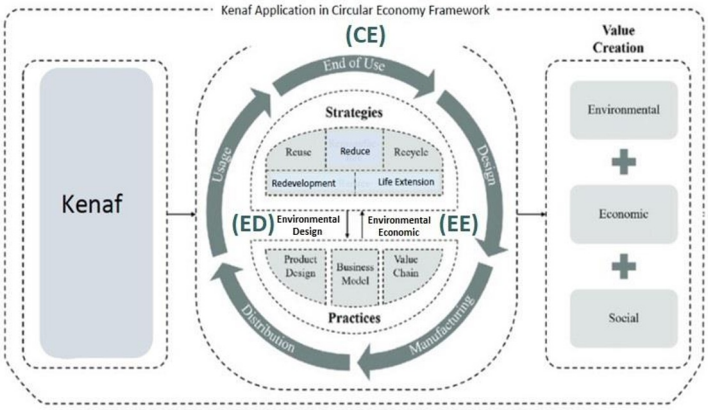

Figure 2. The Relation of Circular Economy in Kenaf Application.

6 Conclusion

Kenaf's application in the circular economy optimizes its environmental, economic, and social factors through environmental economic and design. This helps to minimize the use of resources and emissions, including pollution while encouraging biodiversity and allowing natural regeneration. It compacts the economy by saving on raw material costs, creating new revenue streams, spawning innovation, and reducing the risks of supply-chain fragility. This provides jobs, encourages environmentally friendly practices, and decreases pollution easing the burden on our health. These benefits come about only when we can solve some of the key challenges associated with changes in product design, consumer behaviour, infrastructure development, and policy implementation. If kenaf are to become efficient elements in a circular economy, more research efforts should be carried out regarding their life cycle, impacts on the environment, and climate change comparisons that give basis to standardization of processing methodologies conducive to production consistency and quality, activation of market incentives as well as development policies. Making kenaf better known to consumers and even more investment in technology and infrastructure must be added to the mix for commercial production at scale. Perfected through the steps above, the final result offers a new level of strength in kenaf-based material used in applications such as furniture design allowing for more permanence and reparability like never before. We included some directions for future research that might help to incorporate kenaf into the circular economy. Life-cycle assessments are planned to allow comparison of kenaf to conventional materials, and novel design processes will be studied to reduce manufacturing cycles with communal materials that can have higher durability, repairability, and recyclability properties. Kenaf can be used in a variety of products such as furniture, but further research is necessary to figure out the full potential avenues for this material while analysis of latent Dirichlet allocation (LDA) for Kenaf products in consumer behaviour can create a marketing strategy.

In conclusion, a better policy framework and market incentives for the promotion of kenaf and other sustainable materials need depth of research areas that important to reveal the maximum potential of kenaf in sustaining the sustainable development goals.

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