Prioritization of sustainability indicators for promoting the circular economy: The case of developing countries

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ABSTRACT

The concept of the circular economy has gained well-recognition across the world for the past decades. With the heightening risk of the impact of climate change, resource scarcity to meet the increasing world population, the need to transition to a more sustainable development model is urgent. The circular economy is often cited as one of the best solutions to support sustainable development. However, the diffusion of this concept in the industrial arena is still relatively slow, particularly in the developing country, which collectively exerts high potential to be the world's largest economies and workforce. It is crucial to make sure that the development of these nations is sustainable and not bearing on the cost of future generation. Thus, this work aims to provide a comprehensive review of the circular economy concept in developing country context. Furthermore, a novel model is proposed by adopting Fuzzy Analytics Network Process (FANP) to quantify the priority weights of the sustainability indicators to provide guidelines for the industry stakeholders at different stages of industry cycle to transition toward the circular economy. The results revealed that improvement in economic performance and public acceptance are the key triggers to encourage stakeholders for sustainable development. The outcomes serve as a reference to enhance the overall decision-making process of industry stakeholders. Local authorities can adopt the recommendations to design policy and incentive that encourage the adoption of circular economy in real industry operation to spur up economic development, without neglecting environmental well-being and jeopardizing social benefits.

KEYWORDS

Circular economy, sustainable development, Fuzzy Analytic Network Process (FANP), industry life-cycle analysis, palm oil industry

WORD COUNT

10755 words

ABBREVIATIONS

UN	United Nation
SDG	Sustainable Development Goal
EU	European Union
CE	Circular economy
US	United States of America
UK	United Kingdom
3R	Reduce, Reuse, Recycle
FANP	Fuzzy Analytic Network Process
PwC	Pricewaterhouse Coopers
EY	Ernst & Young
KPMG	Klynveld Peat Marwick Goerdeler
GE	Green economy
BE	Bioeconomy
ROI+20	2012 UN Conference on Sustainable Development that was held in Rio de Janeiro
GGDN	Global Green New Deal
UNEP	United Nations Environment Programme
G20	Group of Twenty
GDP	Gross domestic product
EPU	Economic Planning Unit
WEEE	Waste electrical and electronic equipment
KeTTHA	Kementerian Tenaga, Teknologi Hijau dan Air Malaysia
NKEA	National Key Economic Area
InRP	Indian Resource Panel
MoEFCC	Ministry of Environment, Forest and Climate Change
EFB	Empty fruit bunches
POME	Palm oil mill effluent
KPI	Key performance indicators
ROI	Return on investment
LCA	Life cycle analysis
SME	Small-medium enterprises
MSC Malaysia	Multimedia Super Corridor
ITA	Investment tax allowance
IBA	Industrial building allowance

ACA	Accelerated capital allowance
GTFS	Green Technology Financing Scheme
MYR	Malaysian Ringgit
CP	Cleaner production
SGD	Singapore Dollar
USD	United States Dollar
ANP	Analytic Network Process
AHP	Analytic Hierarchy Process
MCDA	Multiple criteria decision analysis
PE	Pioneering/ emerging
RG	Rapid growth
MS	Maturity and stable growth
DG	Deceleration of growth
EC	Economic cluster
EN	Environmental cluster
SC	Social cluster
CS	Cost
PT	Profit
CF	Carbon footprint
WF	Water footprint
EY	Ecology
HS	Health and safety
ET	Education and training
PA	Public acceptance
PKS	Palm kernel shell
PPF	Palm pressed fibre
GNI	Gross national income
REDII	Renewable Energy Directive
RSPO	Roundtable Sustainable Palm Oil
MSPO	Malaysian Palm Oil Standard
ISPO	Indonesian Sustainable Palm Oil Standard
CSPO	Certified sustainable palm oil

1. Introduction

The heighten concern and uncertainty on the consequences of the world's major issue such as climate change, resource scarcity, energy and food security issues have intensified the need for sustainable development. The concept for sustainable development is first introduced a few decades back by United Nation (UN) (1972) to achieve a balance between economic growth, environmental conservation and preservation and social well-being. It is not until the 2010s that this movement received a strong resonance across the world, particularly with the launching of the 2030 agenda for Sustainable Development Goal (SDGs). SDGs indeed is a big milestone for sustainable development, enlisted 17 objectives to serve as the core of this movement. SDGs cover a wide range of area, ranging from social concern (i.e., no poverty, zero hunger, good health and well-being, quality education, gender equality) to environmental protection (i.e., clean water and sanitation, affordable and clean energy, climate action, life on land), to economic development (decent work and economic growth, industry, innovation and infrastructure, sustainable cities and communities) etc. [1]. As defined by the European Union (EU), *sustainable development focus on the development which meets the needs of the present without compromising the ability of future generations to meet their own needs* [2]. This initiative also strongly emphasises on the cooperation of multiple levels, including local, national, regional and international to form a global partnership to combat the world issues together. In relation to that, different economic models and new concepts have been introduced and promoted to aid the transition towards sustainable development. Circular economy (CE) is amongst one of the popular avenues that are growing recognition in supporting sustainable development initiatives. The idea of CE started way back to 1960s and regained its popularity in industrial and policy arena in recent year, as illustrated in the number of publications of circular economy based on Scopus database literature search, as shown in Fig. 1. There is no clear indication that the concept of the circular economy is drawn from a single source, rather based on multiple ideologies that are well-established years ago. Some of the ideology that contributes to the key principle of CE is the "spaceman" economy – which proposed a cyclical system that encourages the reproduction of materials [3]; "steady-state economy" – maintain a constant amount of inputs (i.e., both materials, human resources, energy) through the product cycle [4], "industrial ecology" – promote the recycled loop of the materials in a designed industrial ecosystem [5] and last but not least, the "cradle-to-cradle" concept – promote recycling with the emphasize on eco-efficiency [6].

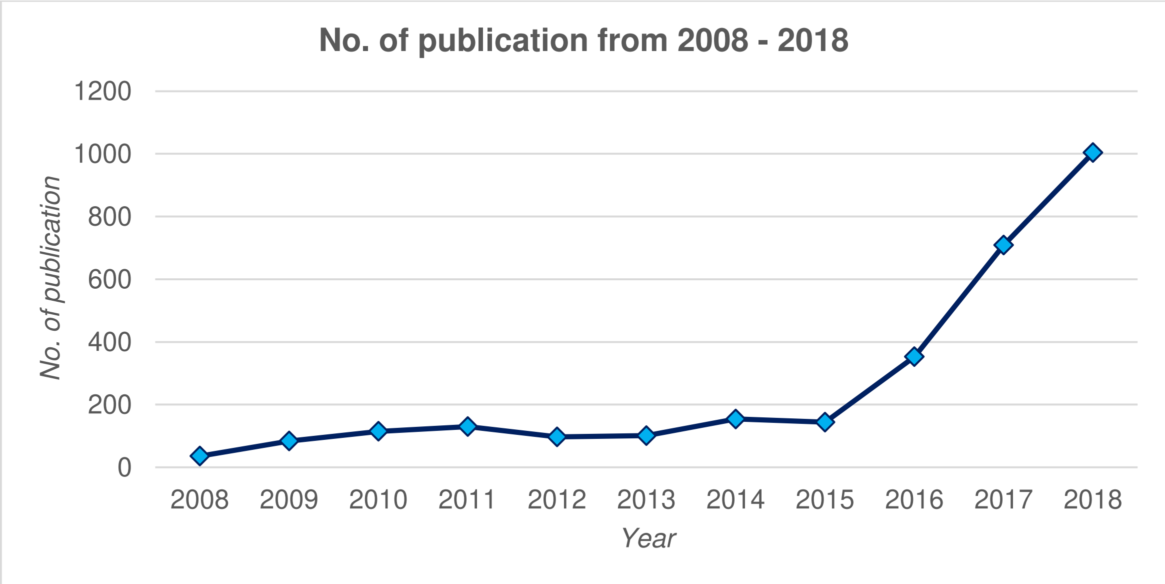

Fig. 1. Number of circular economy-related publication in the Scopus database

However, the concept of CE is often obscure and vary according to different practitioners, field and geographical location [7–9], depending on the cultural, social and political background. For instances, the CE concept in developed nations such as US, UK, European Union nations mainly focus on the 3Rs, reduce, reuse, recycle of the resources, waste management and reduce environmental impact for sustainable development [10]. While developed country in Asia regions such as South Korea and Japan mainly emphasis on the raising public awareness on consumers responsibility on material use and waste [11]. China, on the other hand, adopted the concept of CE to promote urban development and to achieve a balanced growth of the development in the rural area as well as the urban area [12]. The CE-initiative in China highly focuses on the replacement of conventional industrial culture with novel technology and process that significantly increase the efficiency and profitability of the production [13].

CE is not a new term in some niche industry, particularly ecological economics. Nonetheless, there is still a lack of general representation of this notation that is well-accepted and recognized across the world. With an increasing number of practitioners claiming the adoption of CE is useful to spur sustainable development, it is imperative to provide a comprehensive review of the CE concept for implementation. As CE is a relatively new concept to developing countries, especially those who suffer from low-income scenario [14,15], which have higher potential and capacity for economic growth, understanding on the feasibility and practicability of implementation CE in developing countries is very important. Furthermore, to our understanding, existing CE literature as summarized in Table 1thus far is yet to review CE based on the developing country context to provide clear guidelines for the industry players in developing country to transition towards CE for sustainable development. The link between the prioritization of sustainable indicators associated with each stage of the industry life cycle is also vague. Thus, this work proposed the development of a prioritization model with Fuzzy Analytic Network Process (FANP) method in quantifying the dominance relationship of the sustainable indicator for promoting CE in developing countries. This outcome can serve as a framework to help industry players to enhance the decision-making process on the selection of resources to transition toward sustainable development by adopting the CE concept model. It also acts as a reference and recommendation for the policy makers, local and regional authority in designing policy, supports and incentives to encourage the adoption of the CE concept.

Table 1. Highlights of previous reviews of the CE

Author	**Remarks**
Ghisellini et al. [16]	• Reviewed the features and perspectives of CE. • Analysed the implementation of CE at micro, meso and macro level
Blomsma and Brennan [17]	• Highlighted the development of CE concept, with a focus on waste and resource management perspectives
Geissdoerfer et al. [9]	• Compared the conceptual similarities and differences between sustainability and CE
Korhonen et al. [18]	• Examined the definitions of CE • Proposed categorization model for future CE research streams and foci
Millar et al. [19]	• Examined the conceptual relationship between CE and sustainable development • Highlighted and evaluates the capabilities of CE
Saidani et al. [20]	• Proposed a set of need-driven taxonomy for CE

The rest of the articles is organized as follows: Section 2 review on the definition, aim and principles of CE, and the differences with the green economy and bioeconomy. Section 3 presented the methodology for the prioritization model with FANP and followed by Section 4, case selection and descriptions, and Section 5, results and discussion. Lastly, conclusions and future works.

2. Literature review

2.1 Aim and principles for the circular economy

CE which overcomes the constraints of the linear economy of production, consumption and disposal is deemed to be one of the best remedies for sustainable development. In general, CE promotes cyclical resources flows in the production-consumption system. The system is designed to be restorative and regenerative on its own like the cycle and can be applied on a different scale, from micro-level to meso-level as well as macro-system [21]. CE is not a minor change or modification to be added at a certain stage of the industry life-cycle. Rather, it is a fundamental systemic change, regardless of industry, location, scale, nature of business etc. [7]. It proposes a new type of economic growth that involve new business model creation and job opportunities that focus on reducing dependence on the supplier for supply of material, save materials' cost, dampening price volatility [22]. CE limits the throughput flow to a level that nature tolerates and utilises ecosystem cycles in economic cycles by respecting their natural reproduction rates [23]. The prominence action in transforming to CE consists of aspects of reducing, reusing, recycling and recovering material in production/distribution and consumption process to achieve a cradle-to-cradle life cycle. Waste management also plays an important role in the CE to overcome the negative impact of the linear economy, value lost and energy loss [24]. The intention of CE is to phase out "waste" by re-fitting biological and technical waste into the biological and technical materials cycle that designed for remarketing, remanufacture, disassembly or repurposing [25]. Murray et al. [26] also show the hierarchy of the usage of the biological and technical materials in order to keep the materials at their highest value and in use, served as a form of guidelines to ease the transition towards CE. In the research front end, there are increasing number of papers published regarding on CE, ranging from its historical development [11,14], analysis of CE definition [7], application on CE [16,27], explanation on the needs for CE [17], limitation and barriers [8,28] to enablers and implementation tools [22,29]. Besides that the publication from academia, major consulting firm across the world such as Ellen MacArthur Foundation, Pricewaterhouse Coopers (PwC), Ernst & Young (EY), Klynveld Peat Marwick Goerdeler (KPMG) also published various works to aid the industry to transition toward CE.

Nonetheless, some works have presented that there is a poor link between CE and sustainable development [8,18]. From a holistic view, CE that encourages the use of renewable resources, restorative and regeneration of the materials promotes efficient gains and waste avoidance [30]. These concurrently contribute to sustainability in term of environmental improvement and economic profit generation without incurring costs for waste management or purchasing of new resources. However, it is often claimed that the social aspect of sustainability is left out of the CE concept [26,31]. Particularly, the direct enhancement on social well-being aspect through CE implementation is non-obvious, except job creation [7,25]. In [32], Moreau et al. adduced that the norm understanding of the CE concept is lacking in the social and institutional dimensions. On the other hands, the necessity of taking advantages on social enablers in impeding the successful transition to CE is highlighted [28,29]. Raising in social awareness on the needs for sustainable development through formal and informal education, training [30], institutional promotion and support [32] are deemed to be a vital strategy in the implementation of CE.

2.2 Comparison with green economy and bioeconomy

As CE is a relatively new term in developing countries, it often used alternately with other mainstream sustainable development avenues such that green economy (GE) and bioeconomy (BE). Even though these three concepts share some similarities as contributing to either economic, environmental and social for sustainability, there are still some differences that should not be neglect. To avoid the confusion on the coverage and context represent in this work, an overview is done to compare CE notation with GE and BE. This is believed to aid the industry stakeholders in selecting the best operationalization strategies in the path for achieving sustainable development.

A literature search has been performed on December 2018 in Scopus database with the respective string keyword (i.e., CE, GE, BE) to get the number of publications across the years. Fig. 2 illustrated the comparison of CE, GE, and BE related publications for the past ten years (i.e., 2008-2018). It is observed that the number of publications for all these three terms has increased across the years. The number of publications of CE increase tremendously over the past 3 years (i.e., 2016, 2017, 2018), as compared to GE, and BE. Fig. 3 shows the top 10 countries that contribute the most to the CE, green economy and bioeconomy publication. The publication of the articles of BE and GE are concentrated by developed countries, particularly on US, UK, Italy, Germany, Finland, Spain. While the research in CE mainly contributed by authors from China. It is because China is one of the earliest countries who adopted the CE concept in its national development strategy, since the year of 2002. China is also the only developing country enlisted as the major contributor to the literature related to CE, GE and BE. The subject area of the CE, GE, and BE publications are primarily on Environmental Science, Engineering, Energy, Business, Management and Accounting, Social Sciences, and Economics, Econometrics and Finance field.

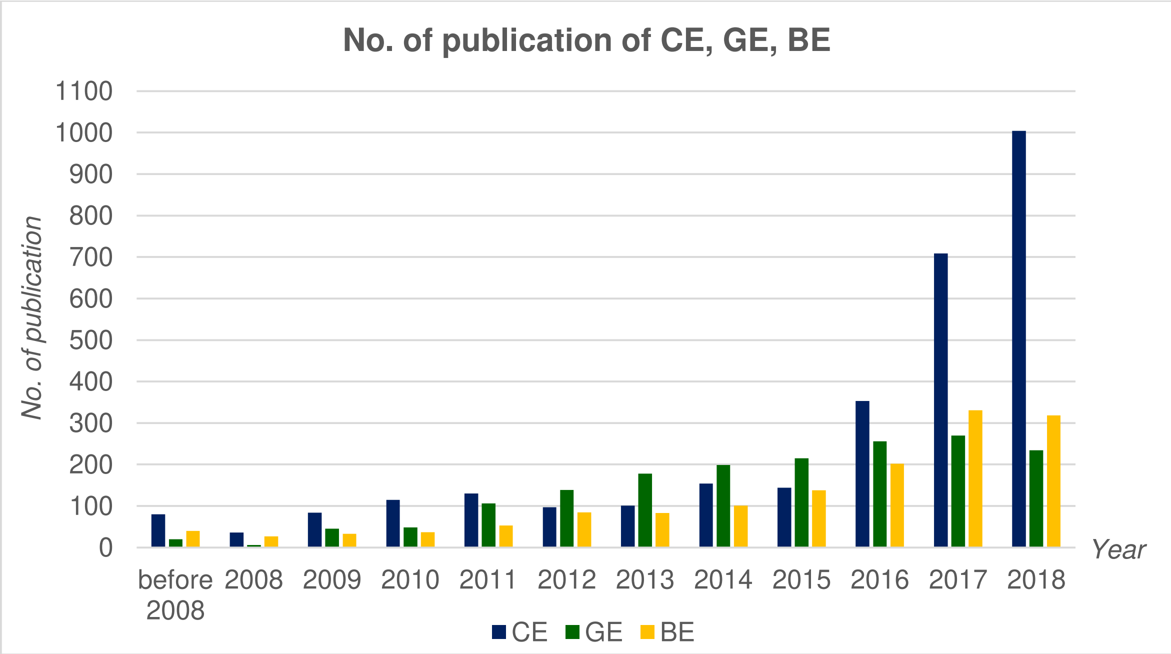

Fig. 2. Trend of the circular economy, green economy, bioeconomy publication for the past 10 years

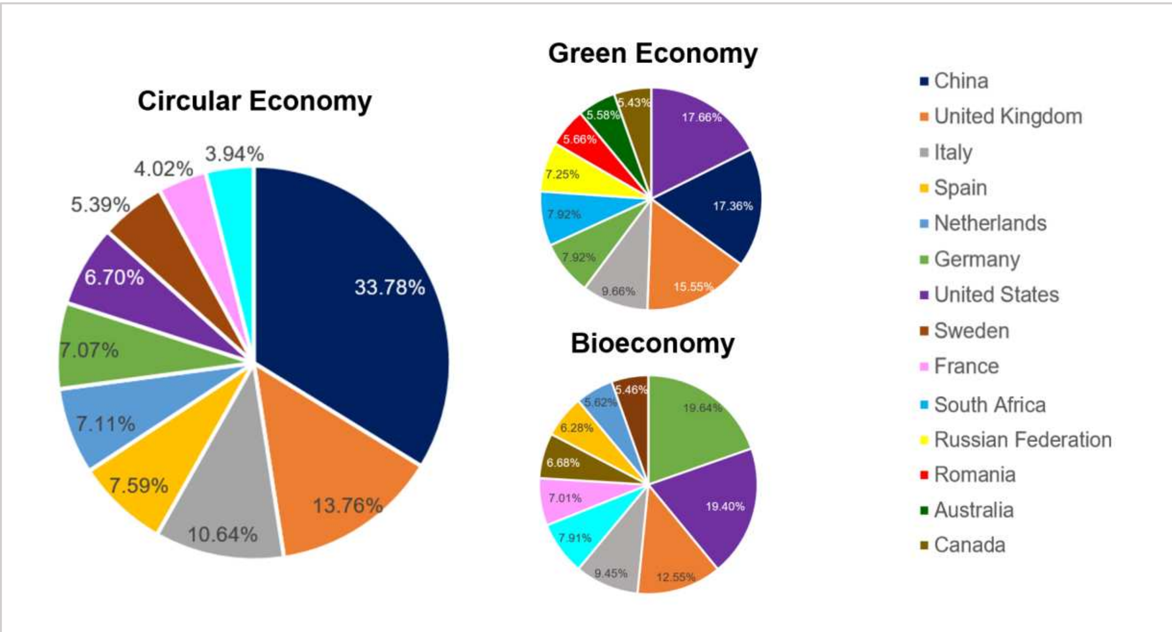

Fig. 3. The top 10 contributions (country) for the circular economy, green economy and bioeconomy publication

2.2.1 Green Economy

The notion, GE is officially introduced in the 2012 UN Conference on Sustainable Development that was held in Rio de Janeiro (ROI+20). It is defined as "*an economic system that results in* *improved human well-being and social equity, while significantly reducing environmental risks and ecological scarcities.*" [33]. The definition of GE conveys the comprehensiveness as the "engine" for sustainable development, which fully covers the economic, environmental and social aspects. It is meant to create a low carbon, resource efficient and socially inclusive economy by invest in natural capital for green projects, and increase energy/resource efficiency [34]. Loiseau et al. [35] described the principles of GE as enable environmental economics, that focus on cleaner production and resource efficiency and ecological economics. The growth in income and the creation of green employment to mitigate social inequality is also a core element in GE in improving the overall quality of life [33]. The most distinctive difference of GE with CE nor BE is that GE goes a step further to drive fund and investment, from both public and private source to kick-start such initiative [36,37]. Global Green New Deal (GGDN), a United Nations Environment Programme (UNEP) movement introduced at the end of 2009 is one of the best example [38]. GGDN engage the 20 most advanced economies (i.e., G20) in the world to invest at least 1% of their total GDP in GE related project. It successful draws a significant amount of investment (i.e., US$ 3.1 trillion) to fund the projects related to (1) energy efficiency in old and new buildings; (2) renewable energy technologies; (3) sustainable transport technologies; (4) the planet's ecological infrastructure; and v. sustainable agriculture [39]. GE heavily promoting the implementation of cleaner energy policy to increase the usage of renewable resources. Large-scale penetration of renewable energy acts as a remedy for climate change, substitution of fossil resources for energy saving, and increase employment of green job to eradicate poverty[40]. GE initiatives also include provides education to raise awareness and acceptance level on the needs of green growth and demand for green products and services. Varying with CE which is relatively new in the policy arena for developing countries, except China, GE has been adopted in multiple developing countries as development blueprint over the past decades [41,42].

2.2.2 Bioeconomy

Bioeconomy is defined by European Commission publication in 2012, "Innovating for Sustainable Growth: A bioeconomy for Europe" as *bioeconomy encompasses the production of renewable biological resources and the conversion of these resources and waste streams into value-added products, such as food, feed, bio-based products and bioenergy [and] includes the sectors of agriculture, forestry, fisheries, food and pulp and paper production, as well as parts of chemical, biotechnological and energy industries* [43]. BE promotes innovative, low-emissions economy while reducing the impact arising for the increasing demand for food, energy to ensure biodiversity and environmental protection [44]. Scarlat [45] illustrate bio-economy as a new growth opportunity in both traditional and emerging bio-based sectors to counter global challenges (i.e., climate change, food security, energy security, scarce resources) with environmental constraints. Bugge et al. [46] categorized bioeconomy into three main groups, namely biotechnology vision, bio-resource vision and bio-ecology vision. Biotechnology vision maximizes the usage of the resources to solve resource shortages and resource scarcity. Bio-resources vision minimizes environmental impact in the process of value creation and bio-ecology vision prioritizes on the hierarchy of the usage of the resources for sustainability. For example, reuse and recycling the waste prior to remanufacture or refurbish for other use. Different with CE and GE concept that emphasizes more on environmental preservation and conversation for environmental impact reduction, BE intends to create new opportunity to transform natural and renewable biological resources for energy, chemicals and materials application and substitution[47]. It is deemed to be more appropriate for rural development, rather than urbanization or industrialization [40]. A few works also described BE as a subset of GE, play an integral role to aid the green growth initiatives [35,48]. Similar to CE, the definition and understanding for BE vary depending on the nature of the industry as well. It has been widely adopted in developed countries, particularly on European nations and America, and receive significantly less attention in developing country thus far.

2.3 Current state of the circular economy in Developing Countries

CE is a relatively new concept in developing countries, excepts G20 nations such as China. Most of the third nations still lack understanding of the synergy that can create with the development of CE for sustainability. In the meanwhile, developing countries, especially those who suffer from the low-income scenario, are facing a growing waste crisis [49]. According to the World Bank Group's report, there are accounted for more than 90 % of solid waste is mismanaged in these low-income countries [50]. Thus, CE which products are recycled, repaired or reused rather than being treated as "waste" has been one of the cutting-edge strategies for the aforementioned issue. The transition to the actual CE requires all stakeholders including industry players, final consumers as well as policymakers to shift from the traditional ways of material usage towards one in which the need of exploitation of primary resources and energy consumptions are being mitigated [51].

2.3.1 Policy and Government initiative

Adequate engagement from the government is crucial in facilitating the implementation of a revolutionary policy. Taking Malaysia as an example, the Malaysia Eleventh Plan has requested a holistic approach for the realization of CE [52]. Table 2 summarized the strategies outlined by the Economic Planning Unit (EPU); while the corresponding responsibilities of all stakeholders are also being highlighted [53].

Table 2. Strategies toward CE in Malaysia [53]

No.	Strategy	Description
1	Prevention and recycling of packaging waste	• Enforcement of Solid Waste and Public Cleansing Act (2007) will increase the recycling rate • A nationwide collection and recycling system have to be established • Labelling of packaging will facilitate the recycling process • Size of packaging and the corresponding compound used should be limited • The “no-free-plastic-bag-day” can be prolonged to seven days a week
2	Ensure 100 % return rate of waste electrical and electronic equipment (WEEE) or e-waste to qualified hands	• The traditional collection cannot provide a 100 % return rate of WEEE • Based on the article listed in Solid Waste and Public Cleansing Act (2007), consumers are responsible to deliver the specified products to the manufacturers, assemblers, importers or dealers • WEEE can be exported to other licensed factories in other countries if necessary
3	Prevention of hazardous waste from entering the biosphere	• Hazardous waste are materials that pose one or more of the four traits (including flammable, reactive, corrosive and toxic) • Consumers shall deliver hazardous wastes back to the dealers
4	Recycling and reuse of the construction waste as the secondary building materials.	• Construction companies must separate wastes on site and convey them to the adequate recycling facilities • Non-compliant dumping of construction waste is prohibited and should be penalised
5	Keeping track of industrial waste	• Industry players have to keep records

		about (i) the types and amount of waste accumulated; (ii) disposal approach; (iii) any measures undertaken based on the 3R principle
6	Foster industrial symbiosis and national waste grid	• Identify the waste stream which might be a valuable resource for other industries • Kementerian Tenaga, Teknologi Hijau dan Air Malaysia (KeTTHA) is developing a national waste grid which allows the sharing of information regarding the available "waste".
7	Valorisation of organic waste and biomass	• The technologies to treat organic waste including composting, bio-gasification and bio-liquefaction require the separate collection of organic waste at the source • Several national policies (e.g., National Biomass Strategy 2020) are aimed to promote the use of agricultural biomass waste for high-value products • Under the National Key Economic Area (NKEA), Malaysian government provides incentives of up to 40 % to local investors for the establishment of biochemical facilities
8	Phasing out direct landfilling	• Malaysia government has attempted to put a stop to the conventional practice of landfilling • Reactive materials are banned from direct landfilling. This will foster the better management of resources in the upstream (e.g., reducing, reusing or recycling)

On the other hand, India government being the sixth-largest economy has also been carried out a favourable regulatory framework to drive the development of CE in India. These macro-initiatives and the related regulations are tabulated in Table 3.

Table 3. Regulatory initiatives to drive CE in India [54]

No.	Policy	Description
1	Zero Defect Zero Effect [55]	• To improve the quality of the manufactured products so that to minimize the number of defects and mitigate the magnitude of their effect on the environment
2	Indian Resource Panel (InRP)	• An advisory body under the Ministry of Environment, Forest and Climate Change (MoEFCC) • Assess resource-related issues facing in India
3	Construction & Demolition Waste Management Rules 2016	• Ensure the construction companies to utilize 10-20 % of the material from construction waste
4	E-Waste Management Rules 2016	• The responsibility of collection and recycling of e-waste lay on the manufacturer
5	Plastic Waste Management Rules 2018	• The manufacture of multi-layer plastic packaging is banned • The plastic waste management fee is introduced to the producers, importers and vendors.

2.3.2 Industry practice

Apart from the national initiatives, some micro-initiatives adopted by the industries are also the crucial enablers for the CE in developing countries. Table 4 shows a summary of some illustrative CE initiatives in developing countries.

Table 4. Illustrative CE initiatives in developing countries

CE Initiatives	Organisation/	Description

	Country	
Palm-based biomass to energy	QL Tawau Palm Pellet Sdn. Bhd. (Malaysia)	Produced palm empty fruit bunches (EFB) pellet for energy generation
Sugarcane molasses-based derivatives	India Glycols Ltd. (India)	Produced bio-chemicals such as mono-ethylene glycol and ethylene oxide
Tractor sharing	Hello Tractor Inc. (Nigeria)	Helped smallholder farmers to improve the agricultural productivity
Bioplastic packaging	Evoware (Indonesia)	Utilised seaweed as the feedstock to generate bioplastic in order to reduce the plastic waste
Refurbishment of IT hardware products	Green Vortex (India)	Involved the collection, segregation, storage, handling and recycling of WEEE
Biomass-based building material	Viet Delta Co., Ltd. (Vietnam)	Utilised rice husks as building material to build more fire-resistant and heat-insulated buildings
Biodegradable plastic	EnviGreen Ltd. (India)	Produced a 100 % organic, biodegradable and eco-friendly plastic bag
Biomass-based paper pulp generation	Thai Gorilla Pulp (Thailand)	Produced high-grade paper pulp from palm EFB
Biorefinery from food waste	Mahinda Group (India)	Utilised city's food and kitchen waste to generate biogas, natural gas and fertilisers
Biogas power plant	Green & Smart Holdings plc (Malaysia)	Utilised palm oil mill effluent (POME) as the source of biogas production.
Food waste to textile product	Singtex (Taiwan)	Converted coffee ground into shirts, socks and other value-added products
Recycling of packaging	Coca-Cola Philippines (Philippines)	Set a global goal to produce packaging that is 100 % recyclable by 2030

2.4 Industry life cycle

Transitioning from the traditional linear model into the CE is theoretically ideal, but there are significant challenges that need to be addressed during industrial implementation. The first step towards the transition is identifying the key performance indicators (KPI) or objectives of the corresponding industrial organisation [56]. Common KPI towards creating a CE are industrial parameters which are closely related to the inherent processing system and supply chain [57]. For example, such KPI may include manufacturing energy consumption, waste emission, carbon emission, return on investment (ROI), cash flow, product demand, raw material supply, etc. Although there are some critical KPI that are important for all types of organization (such as ROI and energy consumption). Although these KPI can be effectively categorized into categories such as manpower, machine, material, money and environment [57], the full list of these KPI usually commonly varies from industry to industry. For example, a nuclear power plant will measure the radioactivity of waste as KPI [58], while a water treatment plant will measure ammonia content in treated water [59]. Current methodologies to assess these KPI can be categorized into life cycle analysis (LCA), material flow analysis, energy analysis, exergy analysis, failure analysis and economic analysis [60,61]. The similarity of these methodologies is that a certain KPI (e.g. energy, economics, emissions, social acceptance) is assessed through the lifecycle of the process and the net gain or loss is determined [60]. These methodologies act as a very solid benchmarking and assessment tools for industrial manufacturing and processing. At this point, the government, policy-makers and even the industrial organization itself can carry out assessment and provide solid KPI values towards CE.

In the industry, the CE does not stop at the boundaries of a single company itself. Traditionally, a company in the industry interacts with their suppliers, contractor and customers in a linear state. This means that the business partners that gives most value will be chosen, and the linear economy will be quickly stabilized into a Nash equilibrium [93, 98]. In the CE, there are multiple companies acting in a complex network fashion where linkages are formed over time [62]. Project collaboration, business partners and industrial relation is at a much more dynamic state than the linear economy [63]. Dynamic management and collaboration between companies in the CE are the challenges. Another major challenge is in measuring who is contributing more to the CE. While KPI values are good for benchmarking similar companies, companies providing different values and function [64] should not be compared apples to apples. This is critically important for the implementation of the CE in any industrial symbiosis as it defines the impartial and just treatment of all companies within the CE. The key is in equalizing the benchmarking line between companies providing different value and function. This terminology was used in a Chinese case study where manufacturing companies were categorized into four types using clustering methods, then assigned CE KPI targets to them separately [65].

The growth of the industrial CE must also be addressed. Referring to examples from the economies of scale, matured and stabilized enterprises obtain major cost advantages due to their large scale of operation [66]. If processing economics and costs are critical inter-related variables within the CE [64], it would give additional advantages to large-scale companies in competing within the CE. Learning from history, the internet economy [67] and the CE shared a similar trait – both are network economy [68]. Today, the internet economy is monopolized by major companies such as Google, Facebook, Amazon and eBay [67]. With the network economy inducing monopoly [69], CE is expected to diminish through time and industrial competition, and the economy would just be monopolized by large enterprises – into a monopolized economy. This phenomenon is already observable at a regional level in Dalian, China [70] where pioneering companies are meeting all national and provincial environmental regulation, while traditional industries are struggling. In Scotland, a micro-brewery start-up produces beers that were brewed from unwanted morning bread roll [71]. The circular start-up faced supply chain difficulties due to their production scale, showing that the economics of scale affects the CE. In China, a company Haier is participating in the CE by recycling e-waste. Despite detailed business planning, the model was not profit-generating (as of 2010) and would only turn profit positive when the economy of scale can be achieved [72]. The needs of closing the circle within the CE has amplified the importance of production volume, giving exponential advantages to large-scale companies. There is an undeniable inclination towards creating market superpowers within the CE (see Fig. 4). It is also likely for such market superpowers to acquire other companies in such an economy where economic costs and environmental impact is prioritized.

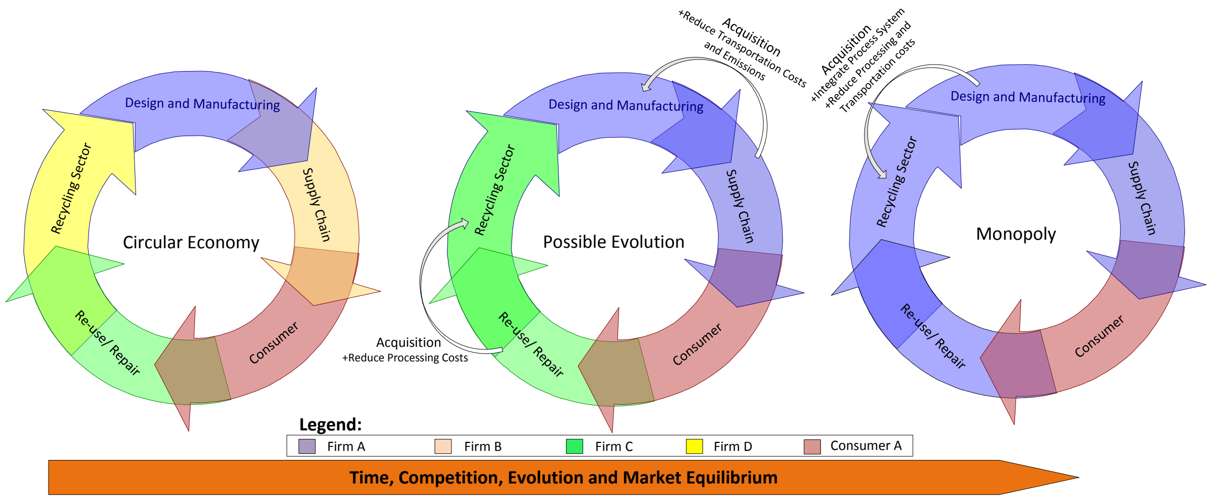

Fig. 4. The possible monopoly of CE due to economies of scale

Again, the solution is to provide incentives and social awareness [70] towards the CE at different stages of the industrial life cycle differently but fairly. The industrial life cycle can be categorized as 4 different stages, which are the pioneering and emerging stage, rapid growth stage, maturity and stable growth stage, growth deceleration stage [73]. The corresponding industrial life cycle stages will be discussed in the subsections below from 2.4.1 to 2.4.4 respectively.

2.4.1 Pioneering and Emerging Stage

Circular start-ups, entrepreneur and small medium enterprises (SME) are common in this stage of the CE [74]. Innovative and novel products and methodologies are often introduced in this phase by companies [75]. The CE in emerging markets often downcycles materials using low labour costs, high losses and poor working conditions [116]. The barrier to entry is the start-up capital and the eco-innovation demonstrated in product and technology [65]. Start-up funding can be obtained from the founder’s own capital, subsidies and grant, Venture Capital, Angel investors, crowdfunding and bank loan [76]. In developing countries such as Malaysia, entrepreneur hubs are available in the Multimedia Super Corridor (MSC Malaysia). Convenience to incentives is available in the hubs to support innovative start-up, which includes pioneer status, investment tax allowance (ITA), research and development grants, industrial building allowance (IBA), accelerated capital allowance (ACA) and other forms of deduction and allowances [77]. The Malaysian Green Technology Financing Scheme (GTFS) has also pooled a 5 billion MYR of funding for green technologies in 2018 [78], which contributes to the development of CE.

The success of the circular start-up is highly associated with industrial risks, which may include environmental, environmental, feedstock, technology and supply chain risks [79]. Yatim et al. concluded that the biomass industry in Malaysia was facing regulatory, financing, technological, supply chain, feedstock, business, social and environmental risks at the pioneering stage [78]. These risks are mainly caused by inconsistent regulations and policies, poor social awareness [80], lack of data for investment evaluation, poor understanding of systems by investors [81] and the requirement for supply chain infrastructure [82]. For the emerging solar cell industry in Korea, a few hypothesis tests were carried out by Park and Kang [83]. They concluded that the entry timing, collaboration activity and technology portfolio affected the product innovation performance during the emerging stage. In Europe, the emerging washing machine industry is reshaped by using sustainable design, pay-per-use business model, predictive supply chain and big data analytics [84]. Process integration was also carried out to improve energy efficiencies within commercial laundries process [85], showing that using up-to-date processing system can effectively debottleneck traditional industries. A systematic approach to energy saving projects in small and medium industrial enterprises was also proposed by Máša et al. [86], which has the potential to accelerate the CE. From a business management perspective, Ellen MacArthur Foundation [25] gave 5 ideas on how breakthrough can be achieved in the circular economies: (1) Tightening circles within the supply chain (2) Enter the market early (3) Activate the community (4) Form networks of cooperation (5) Make profits from arbitrage. These efforts in providing system thinking, implementation frameworks and supportive platforms are driving circular start-ups in the pioneering and emerging stage.

2.4.2 Rapid Growth Stage

Gort and Klepper [75] proposed that the rapid growth stage is defined by a sharp increase in the numbers of producers. This is a period where the innovative industrial product or service has been validated and accepted by the market, causing a rise in competing interests. At this phase, the driving force for firms is the manufacturing innovation by high skilled workers, while manufacturing plants are compact and nearer to consumers [87]. McDougall et al. [88] argued that the sales growth of a company at this stage is critical in maintaining financial performance with the entrance of new competitors. The study also proposed that large-scale entry, speciality products, advertising and promotion, marketing expertise, channels of distribution, brand name and forward integration affected growth in this stage. CE policy is implemented in China to increase synergy between rapid economic growth and resource scarcity [72]. Yuan et al. [89] proposed a three-level approach to implementing CE. The work focused on cleaner production (CP) auditing for micro level, the establishment of eco-industrial networks for meso-level, and development of eco-cities at macro-level. From the work, the establishment of eco-industrial networks was suitable for clusters of companies operating at the rapid growth stage. Such approaches at different level can be effectively mapped to different stages of the industry life-cycle (see Fig. 5). Cleaner production auditing in companies at the pioneering and emerging stage can assess the sustainability of the initial product design and innovation. Involvement of the companies in eco-industrial network and eco-city requires them to be in rapid growth stage and maturity stage respectively to exhibit market volume and stability for business. At the declination stage, companies would need to choose between repositioning their market position or liquidate and decommission. Further details about different stages of the industry lifecycles will be discussed in the later subsections.

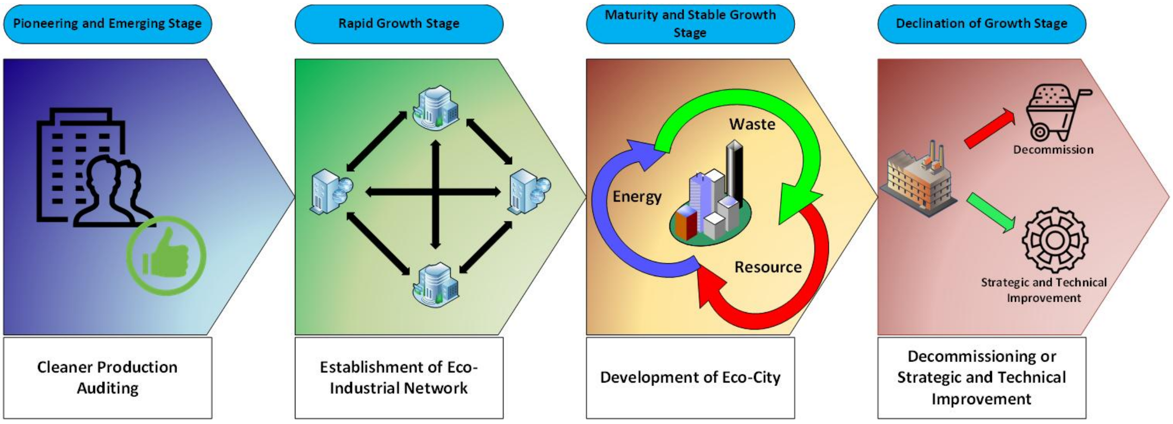

Fig. 5. Stages of Industrial Life Cycle and Implementation Target (an extended concept from Yuan et al. [89]*)*

Works of Park et al. [123] carried out CE business models for three e-waste generating companies (Alcatel, Haier, Dongtai) in China. The study showed that not all companies could generate profit from the eco-industrial network business model and concluded that more financial supports are required to improve the infrastructure. From a survey and analysis on public awareness in Tianjin for promoting CE, the conclusion was drawn that residence classifies waste based on their economic values [90]. The CE clearly requires financing and monetary support for successful implementation. Geng et al. [101] discussed that implementing the CE in a rapid-growing environment faced difficulties in policy changes, technological barriers, and public participation. They also focused that success-leading factors in this phase are suitable corporate models, technologies for promoting and securing investments, the linkage between participating industries, indicators for corporate co-efficiencies and preparing sustainable policies. Later, indicators for corporate co-efficiencies was proposed to be assessed based on 4 groups of criteria, which includes resource output rate, resource consumption rate, integrated resource utilisation rate, waste disposal and pollutant emissions. Valenzuela-Venegas et al. [91] proposed to select suitable sets of sustainable indicators by considering four dimensions, which are understanding, pragmatism, relevance and partial representation of sustainability. The implementation of such indicators proved useful as Li et al. [92] have utilized them in the case studies of chromate production plant, steel manufacturing process and eco-industry in Yima city. Pauliuk et al. [93] showed that the stocking of material affects the CE in the Chinese steel cycle. The work concluded that consumption peak, a temporary oversupply of recycled material, and quality of recycled materials significant slow down the rapid growth phase and transitions the industry into maturity.

2.4.3 Maturity and Stable Growth Stage

The maturity stage is the period where the firms entering and exiting the industry is balanced, approximately zero [75]. Functional and technological standards are achieved by production automation, process equipment specialisation, cost reduction and quality improvement [87]. From works of Yuan et al. [89] the integration of firms into eco-city proposed at a maturity stage. Traditionally, eco-cities refer to cities that were constructed with ideas about urban planning, transportation, housing, economic development, public participation and social justice [94]. However, in the context of CE, it refers to a city that has effort in minimalization of waste, energy and resources [89]. The world's first carbon-neutral zero-waste city was first initiated in 2006 in Abu Dhabi, Masdar City [95,96]. In Dalian, China, the CE policy was regionally implemented in the agriculture, construction and service sector to recover land, water, material and energy resources [70]. The collaboration between China's and Singapore's government has also led to the joint development of the Sino-Singapore Tianjin Eco-city in Tianjin, China [97]. The joint Eco-city cost about 9.7 billion SGD (approximately 7.07 billion USD today) [98], showing that both governmental efforts and humongous development costs are required at this stage.

Fully matured industries such as the waste management industry have waste collection rate positively correlated to the GDP of the country [99], while additional investment costs are required when demand exceeds supply. Another fully matured industry is the waste-to-energy industry, where this technology can convert waste into heat and power while avoiding over-utilization of landfills [100]. Up-to-date waste-to-energy technologies include thermal, energy and off-gas cleaning system which are designed based on rigorous engineering simulations to ensure optimal performance [101]. The matured development of the waste-to-energy industry has flourished beautifully to support the CE on a global scale, and even commercial decision tools are developed [102] for this purpose. LCA [103] points out that waste-to-energy technologies perform better than carbon capture technology towards the CE, as the technology can utilize waste to replace fossil fuels. Still, challenges faced by firms at this stage of the industry life cycle are commonly production overcapacity, loss of production skill due to automation and price competition [87].

2.4.4 Deceleration of Growth Stage

The deceleration of growth phase is defined as the negative net entrant of firms in the industry [75]. Companies in this stage have a low level of product and process innovation, overcapacity in production, require manpower from countries of low labour cost [87]. At this point in the industry life cycle, production is rigid and difficult to cope with the varying environment [87]. Firms normally undergo process improvement, retrofit projects or decommission [104] and more research and development is carried out compared to the matured stage [105]. Management strategies that focus on improving system efficiencies such as "lean and green" [106] are suitable at this stage. Leong et al. [107] have developed a framework for managing manufacturing processing plants with the "lean and green" terminology. Total site utility methodologies can also be used for retrofitting projects [108] and cogeneration designs in total site systems [109] to improve the overall energy efficiency. Lakhal et al. [110] demonstrated an effective "Olympic" framework for green decommissioning of an oil and gas facility. Concepts of the CE was also utilized in oil and gas exploration leading to the utilization of advanced sensors, data analytics, artificial intelligence, analytical methods, drilling technologies and simulation software [111]. The mining industry is also adapting the 3R principles of CE [112]. Cleaner efforts in the mining operation include automation and optimization, improving efficiency, reducing waste (tailing, gangue and wastewater), water reuse and recycle. Mining is also carried out in group mode, ecological park mode or social wide circulation mode to reduce waste in an industrial symbiosis way [112]. The key to managing firms in declination stage is to either improve management and system efficiency or simplify products and service and move to a niche market [87].

Having addressed the distinctive characteristics and challenges of each stage in the industry life cycle, it is pronounced that the implementation of CE in different stages must be carried out with different strategy and policy. With the heightening awareness for sustainable development, it is necessary to make sure that the further development of the world, particularly third nations that still have capacity and resources for growth to be sustainable and long-term. The adoption of various sustainable development, climate change policy without understanding on the stages of the industry life cycle, cultural, political, economic and business background of a country often lead to higher waste of resources and falling short of the target initially determined [113]. Thus, it is imperative to comprehend the structural dependence of the sustainable indicators at different stages of industry life-cycle to derive the priority towards transition for CE. As implementation of CE commonly utilizes CE index [56], generic sustainability index are critically selected to be reasoned, quantified and prioritized. In this work, an analytical prioritization methodology, FANP was used to quantify the complex relationship of the sustainable indicators, stages of the industry life cycle to spur up the uptake of CE in developing country context. The detailed explanation and mathematical formulation of the proposed stages can be found in section 3.

3. Methodology

FANP is a combination of Fuzzy Set Theory [114] and Analytic Network Process (ANP) [115]. ANP is a general form of Analytic Hierarchy Process (AHP), which both were developed by Saaty back to 1980s. ANP and AHP are powerful multiple criteria decision analysis tools (MCDAs) that integrate the structural dependency of a network or hierarchy into a single index. AHP mainly cater to the problems that can be structured into a hierarchy, from top-to-bottom[116]. By structuring the decision-making process into a top-to-bottom form, starting from the goal, main criteria, sub-criteria and lastly alternatives, it allows an independent analysis on the structural dependency for every layer in deriving the final global priority for the alternatives. Unfortunately, most of the real-life issue cannot be structured into a unidirectional issue. It often associated with inner correlation and/or feedback dependence relation. Instead of deriving a single vulnerability index as proposed by AHP, ANP adopted the supermatrix approach to combine all possible relationship in the issue to derive final limiting value. Depending on the nature of the problem and the goal of the decision or study, both AHP and ANP can enhance the overall decision-making process. It is worth to note that this method does not require statistically significant input due to its nature to aid the respective decision makers to systematically analyse the complex relationship to reach a final decision [117]. AHP and ANP have been widely applied in the field of Engineering, computer science, business, management and accounting [118,119].

On the other hand, Fuzzy Set Theory is first introduced to accommodate the "fuzziness" contained in human language (i.e., judgement, evaluation and decisions) [120]. Initially, it is another form "uncertainties theory" that help to deal with the vagueness and ambiguity associated with the real-life, regardless of the performance of technology, resources, materials associated with the human decision. Due to the desirable empirical validation of its output across years, it has been developed into a powerful tool both as a formal theory as well as integrated into different applications or methods to enhance the efficacy of the original method/application. Fuzzy set theory introduces approximate reasoning, release the constraint of binary systems in classical set theory, that only allow either "1" or "0" as an outcome. It permits the membership function-valued in the interval of [0,1], also known as the degree of membership. FANP is one form of the "enhanced" ANP as it replaces the traditional 9-point scale in the inputs for pairwise comparison judgements by fuzzy memberships. Humans can give satisfactory answers, but it rarely can be claimed as an absolute answer due to the existence of much fuzzy knowledge in the real world. The elements that closely associate with human judgements such as expertise and experience tend to have no clean boundary nor single standard to represent by a single crisp value between 1 to 9. Thus, the replacement of the fuzzy membership function to crisp value is deemed to produce a more realistic output [121].

Fig. 6 is the overall methodology flowchart of this proposed work.

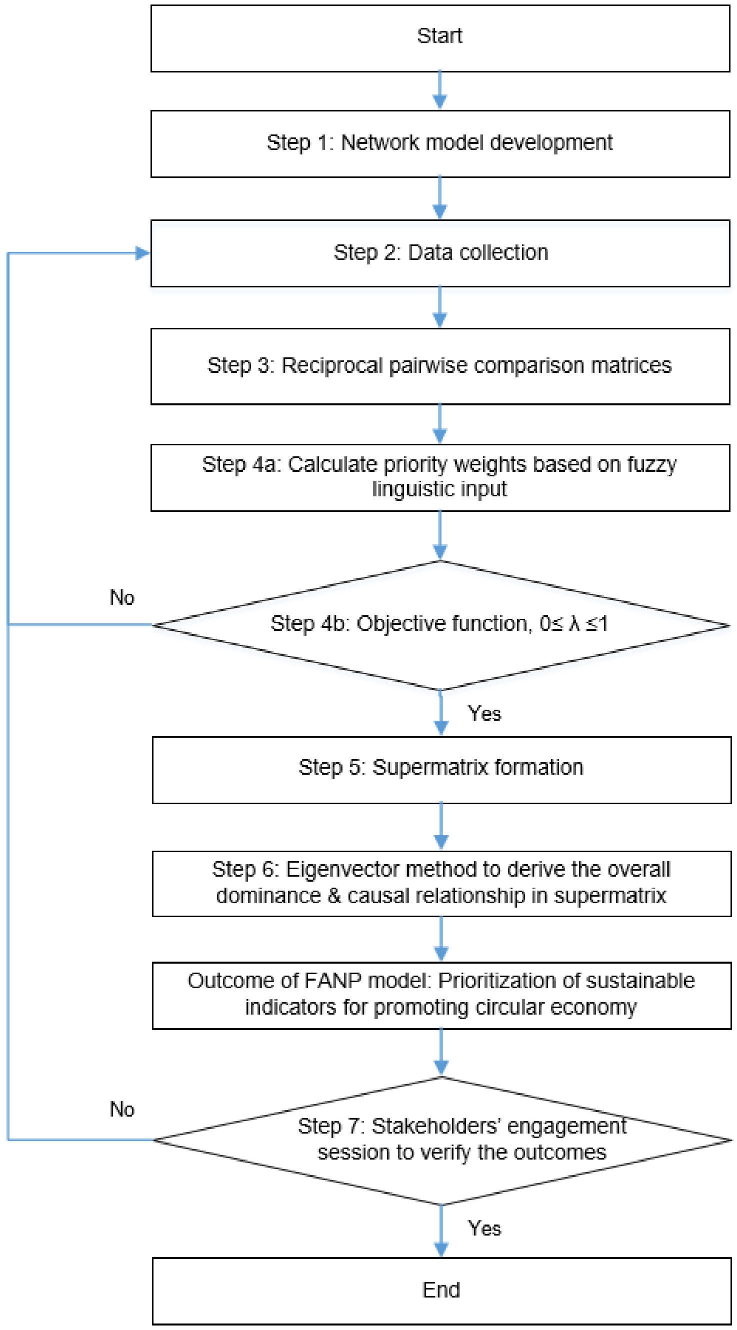

Fig. 6. Methodology flow-chart

Step 1: The relationship of the CE, stages of the business/firm in the industry life-cycle, and sustainable indicators are identified and gathered to develop the network model. The network model is illustrated in Fig. 7. It consists of three different levels, with the first level as the goal, followed by second level, stages in the industry life cycle and lastly, sustainability indicators. The second level consist of 4 different stages of in the general industry life cycle, starting with pioneering/ emerging stage (PE), followed by rapid growth stage (RG), maturity and stable growth stage (MS), and finally, deceleration of growth stage (DG). In term of the sustainability indicators level, it is divided into three different clusters naming economic (EC), environmental (EN), and social (SC). Economic cluster consists of cost (CS) and profit (PT) element; Environmental impact is determined by carbon footprint (CF), water footprint (WF) and ecology (EY) balance; Social dimension is evaluated in term of health and safety (HS), education and training (ET) and public acceptance (PA). The purpose of the model is to prioritize the sustainability indicator to be emphasized for the successful adoption of CE. The direction of the arrows represents different dependency relationships of the elements in the network model. For instances, a downward arrow indicates the direct dependency of the lower level elements with respect to upper-level elements. Self-looping arrows in the cluster represent the interdependence of the elements within the same cluster. Feedback control loop arrows, the arrow that connecting level 2 and level 3 cluster back to the goal cluster (i.e., level 1) is to assure the strong connectivity of all the elements in the model in achieving the goal.

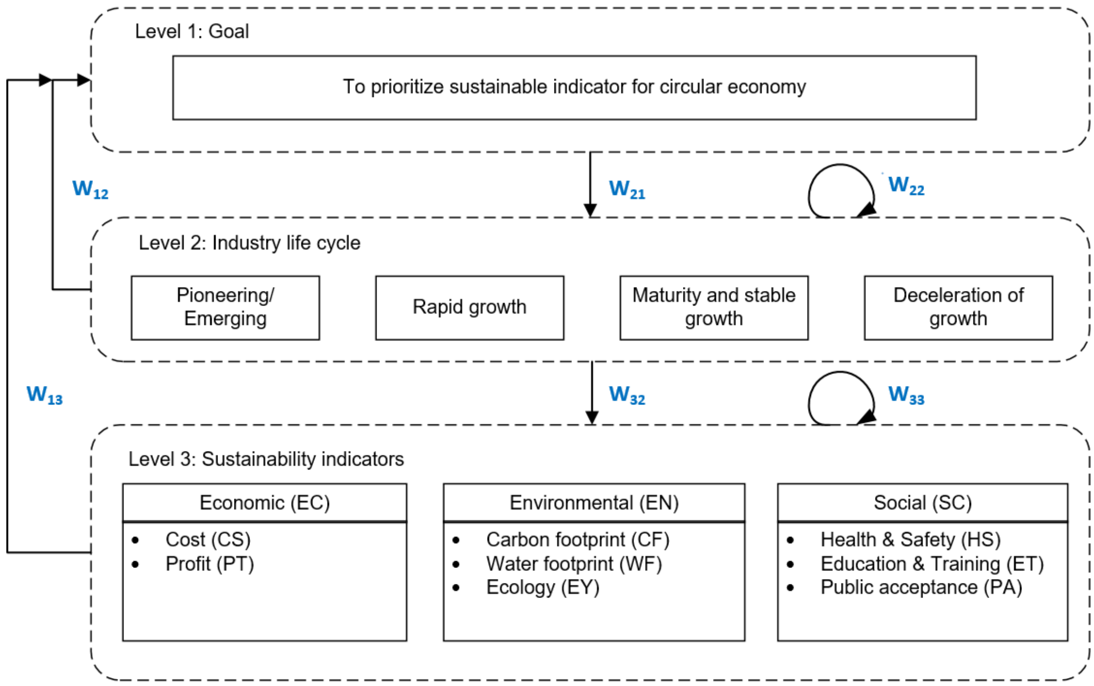

Fig. 7. Representation of the relationships and elements in the network model

Step 2: Data are collected by gathering responses from 20 experts that have expertise and experience on CE-related research. The research areas included but not limited to social-economic benefits of CE, development of cyclical technology and process, optimization for resources saving, energy policy and governance. It is necessary to make sure that the respondents of the questionnaire are competence and proficiency in this subject area to make sure the outcomes are the actual representation of the industry. The questionnaire consists of 3 main parts. Part 1 consists of 6 questions to determine the preference of the stage in the industry life cycle to initiate sustainability practices for CE. Part 2 consists 112 questions to access the importance of different sustainability indicators at a different stage. Part 3 consists of 168 questions to evaluate the interdependence of the sustainable indicator in affecting other indicators in the transition toward CE. The number of questions for each part of the questionnaires is determined by the following formula:

$$\text{Number of questions} = [n(n-1)]/2 \ [116] \qquad (1)$$

where n = number of variables in the level. For example, Part 1 is accessing the preference of the stages in the industry life cycle (Level 2) with respect to the willingness to initiate sustainability practices for CE (i.e., Level 1). There are 4 stages in the industry life cycle (i.e., n = 4). Thus, the number of pairwise comparison questions for Part 1 = [4(3)]/2 = 6. Similarly, Part 2 is evaluating the importance of the sustainability indicators (i.e., Level 3, n = 8) with respect to different stages (i.e., Level 2, n = 4). The number of questions to determine the importance of sustainability indicators at a single stage is 8(7)/2 = 28. And since there are 4 stages in the industry life cycle, the total questions for Part 2 is 4*28 = 112. The same method applied to determine the number of questions for Part 3. The sample questionnaire is attached as a supplementary document for further references. The questions are formulated as pairwise comparison questions, which the researchers are required to compare two elements in pairs and determine the dominance relationship (i.e., preference, importance, influence etc.) based on fuzzy memberships. For example, the pairwise comparison question for Part 2 is formulated as: "For firm or business in the pioneering/emerging stage, which sustainability indicators play a more important role to encourage the transition toward CE and by how much?" Due to the high number of question, calibrated fuzzy scale comparative with its linguistics term introduced by Promentilla et al. [122] is adopted in the questionnaires to ease the responding process. The set of triangular fuzzy numbers and its associated linguistics term is shown in Table5.

Table 5. Fuzzy scale for FANP pairwise comparative judgement

Linguistic scale	Lower bound (l_{ij})	Modal value (m_{ij})	Upper bound (u_{ij})
Equally	1.0	1.0	1.0
Slightly more	1.2	2.0	3.2

Moderately more	1.5	3.0	5.6
Strongly more	3.0	5.0	7.9
Very strongly more	6.0	8.0	9.5

Step 3: The pairwise comparisons inputs in linguistics scale are then converted into vectors, <l, m, u>, representing the lower bound (l), modal value (m) and upper bound (u) of the judgement. It is worth to note that this set of calibrated fuzzy numbers follows Fibonacci sequences, where the range of upper bound and lower bound (i.e., u-l), also known as the degree of fuzziness for stronger dominance relationship (i.e., very strongly more) is larger as compared to weaker dominance relationship (i.e., slightly more). The geometric mean method is then used to aggregate the inputs from responses on the same question. The pairwise reciprocal matrix is illustrated as:

$$\hat{A} = \begin{bmatrix} \langle 1,1,1 \rangle & \hat{a}_{12} & \cdots & \hat{a}_{1n} \\ \hat{a}_{21} & \langle 1,1,1 \rangle & \cdots & \hat{a}_{2n} \\ \vdots & \vdots & \ddots & \vdots \\ \hat{a}_{n1} & \hat{a}_{n1} & \cdots & \langle 1,1,1 \rangle \end{bmatrix} \text{where } \hat{a}_{ij} = \langle l_{ij}, m_{ij}, u_{ij} \rangle \text{ ; } \hat{a}_{ji} = \langle \frac{1}{u_{ij}}, \frac{1}{m_{ij}}, \frac{1}{l_{ij}} \rangle \qquad (2)$$

Step 4: The priority weights of a pairwise reciprocal matrix are computed based on the nonlinear fuzzy preference calibrated Promentilla et al. [123] in 2015. The formulas are as the following:

$$\text{Maximize } \lambda \qquad (3a)$$

s.t.:

$$(m_{ij} - l_{ij})\lambda w_j - w_i + l_{ij} w_j \leq 0, \forall i = 1, \dots, n-1; j = i+1, \dots, n \qquad (3b)$$

$$(u_{ij} - m_{ij})\lambda w_j - w_i + u_{ij} w_j \leq 0, \forall i = 1, \dots, n-1; j = i+1, \dots, n \qquad (3c)$$

$$(m_{ij} - l_{ij})\lambda w_i - w_j + l_{ji} w_i \leq 0, \forall j = j, \dots, n-1; i = j+1, \dots, n \qquad (3d)$$

$$(u_{ji} - m_{ji})\lambda w_i - w_j + u_{ji} w_i \leq 0, \forall j = 1, \dots, n-1; j = j+1, \dots, n \qquad (3e)$$

$$\sum_{i=1}^{n} w_i = 1 \qquad (3f)$$

$$w_i < 1, \forall i = 1, \dots, n \qquad (3g)$$

The objective function is to maximize the degree of satisfactory, λ in calculating the weights of the respective element (i.e., w_i) in the matrix. In the meanwhile, λ also play as the consistency measurement to verify the priority weights calculated are in accordance to the initial response gathered from domains. The value of λ need in the range $0 \leq \lambda \leq 1$. $\lambda = 1$ is elaborate as perfect consistency while $\lambda = 0$ means the judgements are only satisfied at their boundaries [124]. In the event that $\lambda < 0$, it is recommended for the respective expert to revisit their judgments as the inputs are contracted to itself and cannot be concluded.

Step 5: The priority weights derived for every reciprocal pairwise comparison matrices are integrated to form a supermatrix. The arrangement of the priority weights in the supermatrix is illustrated in Table 6:

Table 6. Supermatrix representation

i/j	L1	L2	L3
L1	$w_{11} = 1$	$w_{12} = e^T$	$w_{13} = e^T$
L2	w_{21}	$w_{22} = I$	$w_{23} = 0$
L3	$w_{31} = 0$	w_{32}	w_{33}

w_{ij} is priority weights presenting the direct dependency of the elements in the level i with respective to level j. For example, w_{21} is interpreted as the priority weights of the preference of the stages of industry life cycle (i.e., level 2) in prioritizing sustainable indicator for CE (i.e., level 1). w_{ij} when i=j represents the independent relationship of the elements in the same cluster/level. There are two different types of inner dependence relationships, namely independence and interdependence. Independence relationship means the element only depends on itself, while interdependency means the elements in the clusters have influence power on the other elements as well. As the stages of industry life-cycle are independent of one another (i.e., independence relationship), w_{22} is represented by Identity matrix (i.e., I). The "0", null block matrix (i.e., [0, 0,…,0]) indicates there is no direct relationship between the elements in both clusters (i.e., w_{31}, w_{13}). w_{12} and w_{13} are the priority weights of the feedback control loop, which represented by the unit row vector (i.e., [1,1,…,1]).

Step 6: Eigenvector method is then utilized to power the initial supermatrix until all the value across very column converged. This signifies that all the direct and indirect interaction of the elements in the whole model is taking into consideration in deriving the final weights of the sustainable indicators for promoting CE.

Step 7: The verification of the outcomes generated by the proposed FANP is done by communication with industry stakeholders in focus group discussion setting The stakeholders' engagement session consist of a total of 15 participants, included researchers, industry players, policy makers, and government agency that have expertise and experience in the subject matter to discuss and verify the outcomes from the proposed model. In the event that industry stakeholders failed to reach an agreement with the priority weights and ranking generated from the proposed model, it is recommended to start with the data collection process. It is worth to note that this method enables customization and selection of the elements in the model to cater the generic as well as specific needs of a study, thus, the selection of the questionnaires respondents and verifiers of the result should be highly relevant with the goal.

4. Case selection and descriptions

The palm oil industry is one of the main economic activities in the ASEAN region. Indonesia and Malaysia cumulatively accounted for 85% of the world palm oil production [125], and it is expected to continue to increase in the coming years. The growth of palm oil in Thailand also grow at a significant pace and started to monopoly vegetable oil production [126]. These 3 countries in total produce up to 91% of the total world palm oil [127] and follow by Colombia, which is another developing country. Palm oil is amongst the most popular vegetable oil across the world, contribute about one-third of the global consumption. The consumption rate of palm oil is expected to continue to increase up to 72 million tons per year [128]. Besides than widely used as cooking oil, it can also act as the ingredient in food products (i.e., cookies, margarine, bread spread, pizza dough, bread), cosmetic products (i.e., lipstick, lotion, soap) and further process to become bio-fuel. The ratio of the production of palm oil to dry oil palm biomass waste is about 1:4, excluding palm oil mill effluent [82]. This signifies that for every tonne of the palm oil produced, it produced 4 tonnes of dry biomass (i.e., oil palm trunk, oil palm frond, EFB, palm kernel shell (PKS), palm pressed fibre (PPF) and decanter cake). Malaysia itself produce up to about 100 million dry tonnes of biomass per year. Studies showed that by fully utilized the oil palm biomass into high-value-added products, it could increase the country's gross national income (GNI) by additional MYR 30 billion [129]. Thus, developing the oil palm biomass industry is believed to be one of the best strategies to promote CE to deal with the waste crisis.

Nonetheless, the sustainability of the palm oil industry has been controversial in recent years. The palm oil industry is associated with heavy deforestation which creates a serious impact on the loss of biodiversity. Furthermore, the neglection of the social benefit of labour issues, such as contracted part-time undocumented labour, child labour, women labour, poor working environment also often claimed as a violation of human right [130,131]. With that, a series of anti-palm oil movement has been launched by non-governmental organisations to increase the awareness of the sustainability of palm oil production and avoid the consumption of the palm oil-related products[132]. These create a huge impact on the demand and price for the palm oil in the long run. The situation is worsened with the EU's intention to exclude the import of palm oil from Malaysia (i.e., Renewable Energy Directive (REDII) mandates) [125]. However, the substitution of palm oil with other vegetable oil (i.e., sunflower oil, soya oil etc) might not be a wise move as it required at least 50% more land consumption for the production required to meet the vegetable oil demand [128,132].

Different sets of sustainability standards and certification have been introduced in conjunction with the increasing dispute for this industry. Amongst the certification, Roundtable Sustainable Palm Oil (RSPO) is the most world-recognized. RSPO is the first international organization to develop and implement global standards for sustainable palm oil. It is a multi-stakeholder voluntary international standard that focuses on minimize the negative impact of palm oil cultivation on the environment and communities in palm oil-producing regions. It is firstly introduced in the year 2004 and formally recognized as accreditation in 2013 [133]. RSPO consists of 3 main impact goals and 7 principles on creating sustainable palm oil supply chain, starting from the plantation (supply base) and mill, to the delivery of the palm-oil products to end user. The three impact goals enlisted in the RSPO standards are prosperity (i.e., economic), people (i.e., social) and planet (i.e., environmental) [134]. To ensure the standard is always relevant to the up-to-date context, the standards are revised every 5 years of implementation. Similarly, the RSPO certification owner will need to undergo the main assessment once every 5 years, and annual assessment for continued compliance. The standards and guidelines are also subject to national interpretation due to the difference in law and regulations in the different country. RSPO also consists of seven principles in total. Impact goal "Prosperity" consists of three principles, to create a competitive, resilient and sustainable sector: behave ethically and transparently; operate legally and respect rights; and optimise productivity, efficiency, positive impacts and resilience. Impact goal "People" aims to create sustainable livelihoods and poverty reduction with the following three principles: respect community and human rights and deliver benefits; support smallholder inclusion; respect workers' right and conditions. The last principle is categorized under impact goal "Planet" to conserve, protect and enhance the ecosystem that provides for the next generation through protect, conserve and enhance ecosystems and the environment [134].

Another two sustainability standards that are commonly known across the industry are Malaysian Palm Oil Standard (MSPO) and Indonesian Sustainable Palm Oil Standard (ISPO). These two certifications are introduced as voluntarily basic by respective local government and later enacted as law to mandate compulsory compliance. MSPO was first launched in November 2013 and officially came into effect by 2015. MSPO consist of 2 major categories, oil palm management certification and supply chain certification. Oil palm management certification consists of three parts, for independent smallholders, oil palm plantations and organised smallholders and palm oil mill. The standards and criteria for the respective category are varied slightly. The first six (6) key principles for all these three categories are the same, management commitment and responsibility, transparency, compliance to legal requirements, social responsibility, health, safety and employment conditions, environment, natural resources, biodiversity and ecosystem services, best practices, except for the seventh, development of new plantings is excluded for palm oil mill as it is not relevant [135]. On the other hand, the supply chain certification under MSPO was just newly introduced and officially come into implementation in August 2018. Similar to RSPO certification, supply chain certification applies to industry players that process, trade or manufacture palm oil products. The Supply Chain Certification Standard focuses on the transparency and traceability of the information and material/product flow throughout the supply chain to ensure all stakeholders carry their responsibility to ensure the sustainability of the supply chain [136]. On the other hands, ISPO also consists of seven principles, namely licensing system and plantation management, technical guidelines for palm oil cultivation and processing, environmental management and monitoring, responsibilities for workers, social and community responsibility, strengthening community economic activities and sustainable business development [137]. ISPO contains 3 types for certifications which are grower certification, supply chain certification and holding certification.

There is a lot of effort has been directed by the local governments, volunteer organization such as RSPO to guide industry stakeholders to compliance with sustainable practices. However, the uptake level of the industry players voluntarily in compliance with such sustainability standards are still relatively low, especially small stakeholders, which accounted for 38% [138] and 40% [139] of the ownership of oil palm cultivation in Indonesia and Malaysia respectively. The stage of industry life-cycle which the firm/plantations are in also greatly affecting the cost and impact to uptake sustainability practice in its operation. Thus, this case study applied the proposed model in the palm oil industry to prioritize the sustainable indicators at each stage of the industry life-cycle to promote CE in developing countries.

First, the network model as illustrated in Fig. 7 is adopted to prioritize the sustainable indicator for the palm oil industry to adopt CE for sustainable development. A well-mixed of palm oil industry stakeholder which consists of oil palm plantation owners, palm oil-related business/firm owners, sustainability standard certification auditors and researchers who working on sustainability studies are engaged to respond to the questionnaires. The pairwise comparison question is structure as "Based on the general palm oil industry life cycle, which stage of the project/business is more preferred to initiate sustainability practices in its operation for the circular economy?". The data collected is filtered to make sure completeness prior proceed with the calculation. The calculation to generate the priority weights for pairwise reciprocal matrices are computed based on the equation (2) – (3) with the LINGO 16.0 application.

A simple numerical example based on one respondent (i.e., R1) is given to demonstrate the proposed method. Table 7 illustrated the pairwise comparison matrix of R1 with the derived priority weights of the preferences of stages on industry life-cycle to initiate sustainability practices in its operation for the circular economy. The values <1/3.2, 1/2, 1/1.2> on row 2, column 3 are interpreted as L2-RG is slightly more preferred than L1 – PE to initiate sustainability practices in its operation for the circular economy. The $w_{21\text{-}R1}$ column represents the priority weighs calculated based on Equations (2-3). The w_{21} calculated based on the inputs of all respondents aggregated with the geometric mean method will serve as one of the column block entries to the supermatrix, as illustrated in table 6. λ is the measurement of consistency of judgements given by R1.

Table 7. Supermatrix representation

GOAL	L1-PE	L2-RG	L3-MS	L4-DG	$w_{21\text{-}R1}$
L1-PE	<1.0,1.0,1.0>	<1/3.2, 1/2, 1/1.2>	<1/3.2, 1/2, 1/1.2>	<1.0,1.0,1.0>	0.1667
L2-RG	<1.2, 2.0, 3,2>	<1.0,1.0, 1.0>	<1.0,1.0,1.0>	<1.2, 2, 3.2>	0.3333
L3-MS	<1.2, 2.0, 3,2>	<1.0,1.0,1.0>	<1.0,1.0,1.0>	<1.2, 2, 3.2>	0.3333
L4-DG	<1.0,1.0,1.0>	<1/3.2, 1/2, 1/1.2>	<1/3.2, 1/2, 1/1.2>	<1.0,1.0,1.0>	0.1667

$\lambda = 0.9999$

5. Result and Discussion

The priority weights of every relationship derived from individual reciprocal pairwise comparison matrices (i.e., Step 3-4) and the final converged value (i.e., Step 5-6) and its ranking are shown in Fig. 8. The value in the supermatrix can be interpreted in three different dimensions: i. priority weights of direct dependency relationships, as highlighted in blue and green colour; ii. Inner dependency relationship of sustainability indicators, as highlighted in orange; and the iii. comprehensive weights for the whole model, portraying at the final value column. The industry stakeholders concurred the results as illustrated in Fig. 8, with additional comments included in the discussion.

	GO	L1-PE	L2-RG	L3-MS	L4-DG	EC-CS	EC-PT	EN-CF	EN-WF	EN-EY	SC-HS	SC-ET	SC-PA	**Final value**	**Ranking**
GO	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000		
L1-PE	0.2774	1.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	**27.74%**	**2**
L2-RG	0.2285	0.0000	1.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	**22.85%**	**3**
L3-MS	0.4135	0.0000	0.0000	1.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	**41.35%**	**1**
L4-DG	0.0806	0.0000	0.0000	0.0000	1.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	8.06%	4
EC-CS	0.0000	0.2919	0.1391	0.0885	0.1838	1.0000	0.1368	0.2034	0.1984	0.1397	0.1556	0.1133	0.1530	**14.85%**	**1**
EC-PT	0.0000	0.1722	0.2032	0.0979	0.1259	0.2905	1.0000	0.1767	0.1984	0.1246	0.1379	0.1638	0.1190	**14.75%**	**2**
EN-CF	0.0000	0.0803	0.1149	0.1202	0.0853	0.1206	0.1392	1.0000	0.0919	0.1993	0.1148	0.1200	0.1077	10.95%	7
EN-WF	0.0000	0.0669	0.1091	0.1247	0.0839	0.1291	0.1677	0.1089	1.0000	0.1879	0.1148	0.1200	0.1657	11.47%	5
EN-EY	0.0000	0.0909	0.1048	0.1247	0.1316	0.1128	0.1246	0.1639	0.1984	1.0000	0.0956	0.1819	0.1724	12.11%	4
SC-HS	0.0000	0.1082	0.0863	0.1030	0.1361	0.0917	0.1085	0.0878	0.0817	0.0906	1.0000	0.1776	0.1752	10.39%	8
SC-ET	0.0000	0.0608	0.0899	0.1528	0.1338	0.1124	0.1460	0.0845	0.0869	0.0970	0.3037	1.0000	0.1070	11.36%	6
SC-PA	0.0000	0.1288	0.1528	0.1883	0.1195	0.1429	0.1772	0.1749	0.1442	0.1609	0.0775	0.1234	1.0000	**14.13%**	**3**

Fig. 8. The supermatrix table and its final value and ranking

Fig. 9 illustrates the network relationship of the CE goal, industry life cycle phases, and prioritization indexes. Weights of each node indicate the percentage importance value, while the thickness of each connection edge indicates the average dependency relationship. Based on the outcomes, "L3-MS" stage appeared to be the best stage to initiate and implement sustainable practices in its operation for CE, followed by "L1–PE" stage, "L2-GF" stage and finally, "L4-DG" stage. The segmentation of the industry life cycle is adopted from Hill and Jones [140] which divided the industry life cycle into four different stages, with applications for both firm level as well as an industry as a whole system. The PE stage is described as the introduction of new technology or product in the market. This stage tends to associate with high upstart costs, with low demand due to the "newness" of the product and industry. It is also the surviving stage for the new entrant on whether able to play a role in this industry or market [141]. Firm and industry in RG stage experience accelerated sales and profit. It is the stage where the market experience the highest level of heterogeneity between firms, such as product variation and market share instability for the emerging of market leader [142]. MS growth stage occur when the competition started to wane as the firm identify and understand its competitive advantage in the market and fully utilize it. In most of the case, the firm will produce at its economic of scale to fully portray its competitive advantages. This stage also tends to be the longest stage in the life cycle whereby norm and standard will be formed, and the weak competitors will be eliminated in the market [143]. Porter [144] describe that the same force of competition will continue and intensify rivalry, until the industry experience lower intra-industry homogeneity, this is when the industry moves on to the last stage, the deceleration and declining stage. This stage is not a representation of the poor performance of the industry/ firm, it is the stage where the market is concentrated with few key players, with lack of variation for further innovation or breakthrough [145]. Thus, the growth rate started to remain stagnant or even slowing due to the satiation of demand. It is also the stage where the industry will experience a change in consumer preference and demand shifts to new products or substitutes.

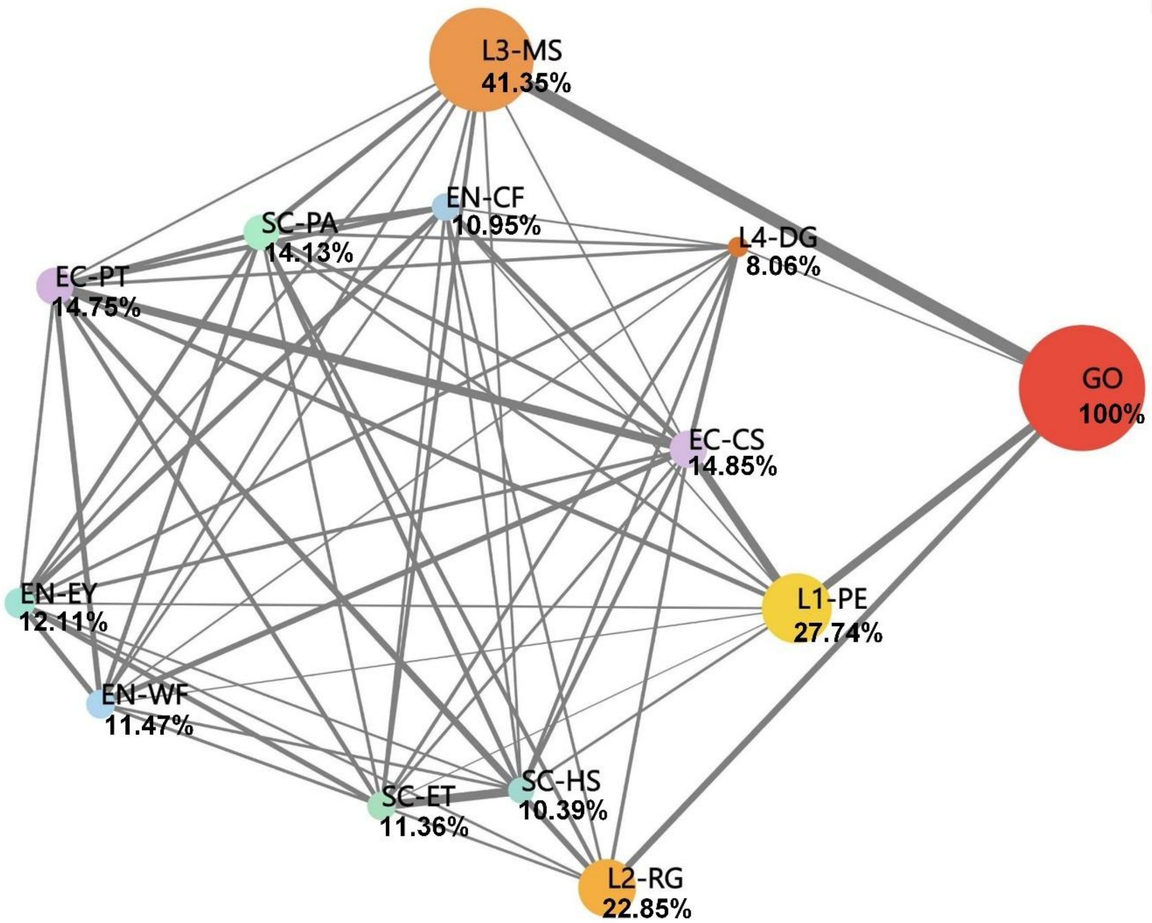

Fig. 9. Network visualization of ANP relationship

The focus group participants concurred with the outcome in which the MS stage is the best stage to uptake sustainability practices for CE. It is because the business and firm in this stage have sufficient capacity and ability, both in term of capital as well as human resources to sustain its operation. This enables the firm to divert its full attention from economic benefits to focus on environmental well-being and social responsibility. Furthermore, the firm in MS stage also contains sufficient data and information to undergo fundamental change proposed by CE framework [29].

Some of the recommendations to initiate sustainability practices are the replacement of inefficient and less effective technology to cleaner technology, optimise the process through leveraging the history data for minimizing waste of energy, reduce redundant parts, encourage sharing of resources etc. [146]. These efforts do not only help to reduce long-term operation cost, gain reputations as an environmental and socially responsible party, it also served as an alternative to prevent the company to fall into next stage, the DG stage. The PE stage is ranked 2nd in the list. Business or firm in the PE stage is the most flexible stage across the industry life cycle to shape its competitive advantage to survive in the market [142,144]. Even though the risk profile for the CE business model in developing countries is higher as compared to the conventional model due to the lack of a successful precedent case, the long-term benefit is significant. Particularly, economic gain through reduced raw material and energy costs, waste management cost, emissions control cost, and blue ocean market creation and environmental preservation through reduction on virgin materials and resources input, while reducing the overall wastes and emissions [8]. These are deemed to be a powerful strategy in moulding the image and development blueprint of the business and firm. Furthermore, with the growing resonance of SDGs in a global arena, there is also a high possibility for mandatory compliance for sustainable standards in the near future. By adopting sustainable operation at the initial stage can reduce the compliance cost in the future.

In term of the importance of sustainability indicators in encouraging the transition toward CE throughout the whole industry life-cycle, CS is the top factor, followed by PT, and PA. The first two indicators are from the EC cluster. This indicates that economic gain is still the key driver for the stakeholders in the palm oil industry to adopt and integrate sustainability components in its operation, across the palm oil supply chain. It is also often cited as one of the factors that hindering small stakeholders in Malaysia and Indonesia to voluntary compliance to MSPO and ISPO, as all the principles of the certifications merely focus on environmental and social aspects [135,137]. This finding can serve as a reference for local authorities and policymakers to incorporate economic element in is to attract the uphold of such standards. For example, certified sustainable palm oil (CSPO) awarded by full compliance with RSPO is able to sell at a higher price (i.e., >10% premium) as compare to non-CSPO [147].

PA ranked 3rd in the sustainability indicators that should be prioritized to promote CE. The arousing confrontation on the environmental destruction caused by the palm oil industry has in recent years has intensified the anti-palm oil movement. This series of movement has, directly and indirectly, affected the demand and price of the palm oil [125], particularly the demand on developed nations where the community has high awareness on purchasing products sourced from sustainable palm oil [132]. One of the examples is the increasing demand for CSPO. Even though CSPO only accounted only less than one-fifth of the total world palm oil production, there has been a clear trend on the higher demand despite the need to pay a premium. A recent work, Pischke et al. [148] also further assure the importance of public acceptance in affecting the purchasing and consumption behaviours of palm oil, and the growth of the whole industry. Azima et al. [149] emphasized the importance of social interaction in assuring the non-disruptive palm oil production chain. Another example of the importance of public acceptance is reflected by the increasing trend at developed countries on community financing. With the high public acceptance and awareness on the need for renewable energy, community is willing to finance the renewable energy project which is deemed as high risk and low return investment [150]. Thus, in order to encourage the uptake of sustainability practices in the oil palm industry, there is a need to raise the public acceptance on the sustainable palm oil, but not based on the value of money [151]. EY and WF are ranked 4th and 5th, followed by ET, CF and lastly HS. It is crucial to understand that the goal of this study focuses on prioritization of the sustainability indicators to promote CE, thus, the indicators with lower weights are not insignificant for the overall development of the industry. It only provides recommendations for the industry players to design and select an action plan to spur up the sustainability of the industry based on the indicators that have higher preferences.

The sustainability indicators that carry the highest weights for each stage of industry life-cycle are varied slightly as illustrated in Fig. 10. For the PE stage, RG and DG stage, the top indicators are mainly dominated by EC cluster's elements, CS and PT. For MS growth stage, it is interesting to note that the preferences have shifted from economic benefits to environmental and social well-being. PA carries the highest weights, followed by ET. WF and EY share the same weights to rank at the 3rd, simultaneously, with CF have slightly lower weights after WF and EY. This further affirms the finding firm in the above section that firm or business at MS growth stage is the most suitable stage to initiate such transition as they have sufficient resources to shift its objective from profit-oriented to social and environmental oriented.

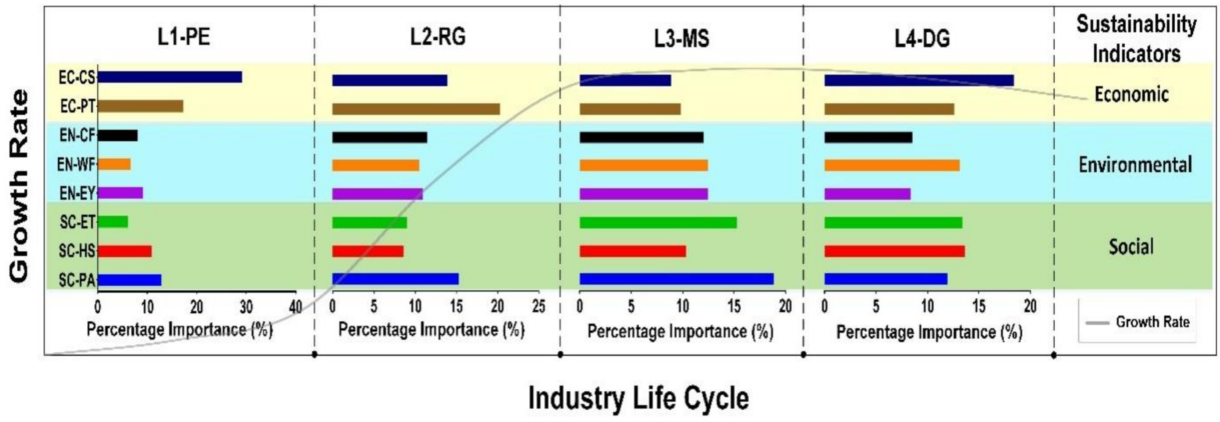

Fig. 10. Importance of CE sustainability index in each stage of the industry life cycle

In term of the power of influence, it is observed that the economic cluster, both cost and profit are the indicators that have highest influences on other sustainable indicators. Ecology factors are next on the list. The analysis of the power of influence can serve as a reference for the industry stakeholder, particularly decision makers and policy makers to design and customize action plan and incentive or support to boost the indicators with a higher power of influence. By accelerating the performance of indicator which has a high power of influences is expected to improve the performance of other indicators, concurrently.

6. Conclusion

CE is no doubt one of the best sustainable development framework for developing country to solve waste issues and simultaneously avoid further development bearing on the cost of environment and resources of the future generation. The work provides an overview of the CE for developing country, with in-depth analysis of the strength and weaknesses of feasibility and practicality of transition into the CE model in general industry life-cycle. A FANP model is proposed to prioritise the sustainable indicators to aid the industry stakeholders at different stages of the industry life cycle to ease the transition towards CE. The results based on the oil palm industry case study shows that economic performance indicators (i.e., CS, PT) still play a dominant role in encouraging the industry players to adopt sustainable practices to promote CE, followed by PA. This indicates that economic benefits and public acceptance play a prominent role in affecting the decision of industry players towards CE. The outcomes served as a reference for the government agency, policy makers or non-governmental organization to incorporate such elements in its policy and plan to encourage fast adoption for CE for sustainable development. As the data for the model is gathered based on the expert's input, it is worth to note that the outcomes might varies depending on the background, expertise and experiences of respondents. Nonetheless, this is also one of the pros of the proposed model as it served as a generic decision-making model to take in complicated structural dependency (outer-dependency, interdependency) in deriving the final output, regardless for niche group (firm level) or an industry as a whole. The performed study and method can also be extended into other expects of CE development, such as comparison of the factors and priority in promoting CE between developed and developing countries.

Conflict of interest statement

Declarations of interest: none

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