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Review article

The Bio-Circular Green Economy model in Thailand – A comparative review

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Abstract

Importance of the work: Thailand is seeking to develop a Bio-Circular-Green (BCG) economic solution to mitigate the effects of CO_2 emissions.

Objectives: To understand the strategic activities required to lead Thailand to a future sustainable bio-circular economy in comparison with other countries.

Materials & Methods: Data was collected from journals, literature reviews and on-line reports. Impacts on a BCG economy are analyzed by SWOT analysis for economic, environmental and energy impacts. The results inform the conclusions, recommendations on policy, R&D and future work.

Results: Thailand and many countries are moving towards a circular economy and sustainable development. The elimination of waste and the use of renewable resources are important for future consumption and the wellbeing of the people. The Bio-Circular-Green (BCG) Economy Action Plan is a good example of moves to create innovation and to drive the economy into a future "new normal" environment. Implementation needs concrete projects, suitable initial funding and industry incentives: time is short. Actions toward a more sustainable future must also recognize and share good practice. Enhancing networking between countries and regions benefits the citizens, communities, public and private sectors and helps to create income. R&D projects have to be capable of pushing forward regional, national and global goals.

Main findings: Thailand and other countries have policies to develop a BCG economy. However, they differ in approach and application and require better international co-ordination and understanding.

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Introduction

A BCG economy can be described as a system that tackles global challenges through a model of economic, social and environment production and consumption that aims to build a sustainable society based on developing bioproducts and using waste in a closed loop system through approaches such as reduction, reuse, recycle etc. (National Science and Technology Development Agency, 2021c). The concept can be applied to all sectors and activities and integrated to cover a whole community or country.

A circular economy consisting of an economic system of returning, reuse, sharing, repair, refurbishment, remanufacturing and recycling will create a closed-loop in the production system. It differs from the traditional linear economy which moves from raw material through product manufacture, use until disposal and the creation of waste. There are many concepts that can be encompassed by the circular economy. The zero waste concept focuses on the production of goods without waste, including their source material (which may be a by-product or "waste" product of other processes) and waste management; re-purposing "waste" to close the loop of the system as shown in Fig. 1 (Wautelet, 2018; Danjou, 2020). The zero-waste concept essentially aims to do away with the idea of "waste". What was once waste now becomes a raw-material.

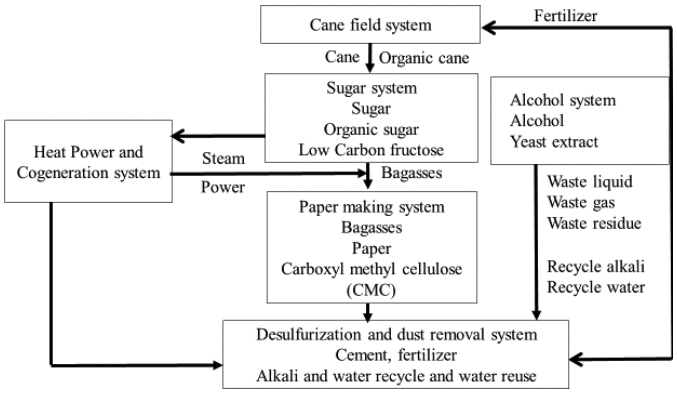

Fig. 1 Circular economy model for sugar industry (Li and Lin, 2016)

Other approaches (for example that given by the European Forest Institute) emphasize that a circular bioeconomy relies on a healthy, biodiverse and resilient economy. It should aim to provide sustainable wellbeing through the provision of ecosystem services and the sustainable management of biological resources such as plants, animals, micro-organisms and derived biomass, including organic waste (Ekins et al., 2019). These are transformed in a circular manner into food, feedstocks, energy and biomaterials all within the ecological boundaries of the ecosystem from which they are derived (Palahi, 2021).

The idea of a circle of materials or energy was mentioned in 1941 in a book by Kenneth E. Boulding, who explained that societies should be in a "cyclical system" of production (Boulding, 1966). Later it was addressed as the "circular economy" by Allen V. Kneese in 1988 in "The Economics of Natural Resources" (Kneese, 1988). It also appeared in "A circular Economy Model of Economic Growth" by Donald A.R. George and colleagues in 2015 (George et al., 2015). Three principals were expounded: (1) diminish waste and pollution; (2) keep products and materials in use and (3) regenerate the natural system. Vanhamaki et al. (2019) have categorized the circular economy as having three levels: (1) the macro level (e.g., entities such as the European Union, individual nations, regions or cities); (2) the meso level (local ecosystems and industrial networks) and (3) the micro level (companies and consumers).

A "green" economy is defined as low carbon, resource efficient and socially inclusive. In a green economy, growth in employment and income are driven by public and private investment into economic activities, infrastructure and assets that allow reduced carbon emissions and pollution, enhanced energy and resource efficiency, and prevention of the loss of biodiversity and ecosystem services (UN Environment Programme, 2022).

The Bio-Circular Green (BCG) Economy

A Bio-Circular Green Economy puts renewable natural resources at the heart of the economy. The name 'BCG' encompasses the bioeconomy as the production of renewable biological resources and their conversion into value added products, the circular economy as the reuse and recycling of resources and the green economy as keeping economy, society and the environment in harmony, resulting in sustainable development (Mahanakorn Partners Group, 2021).

The BCG economic model was developed in Thailand to form a part of the Thailand 4.0 policy as a way to encourage economic and social development and help meet CO_2 targets. The model integrates bio-, circular, and green economies, building on Thailand's strengths in agriculture and natural resources, diversity and geography. Thailand's BCG conforms to UN sustainable Development Goals (SDGs) in striving for the conservation and sustainable use of biodiversity and protection of natural resources and ecosystems.

During Thailand's Asia Pacific Economic Co-Operation host year, the Bio-Circular-Green (BCG) Economy concept was introduced into APEC's conversation as a promising post-pandemic growth strategy where science, innovation and technology are applied to promote the efficient use of resources, maintain and restore ecosystems, and reduce waste to build a thriving "new normal". It aims to contribute to the global efforts of comprehensively addressing all environmental challenges for a sustainable planet (Asia-Pacific Economic Cooperation [APEC], 2022).

The 2022 APEC Leaders meeting (18–19 November 2022) endorsed the Bangkok Goals on the Bio-Circular-Green (BCG) Economy. The Bangkok Goals cover climate change mitigation, sustainable trade and investment, environmental conservation and waste management, and is a comprehensive framework to further APEC's sustainability objectives.

A BCG model is necessary in Thailand because the concept of a circular economy can help to use natural resources most efficiently. Thailand has an abundant capacity for plant based natural resource production and is following the global concept of reducing CO_2 emissions by focusing on five developing sectors: food, healthcare, sustainable energy, tourism and the creative economy (Royal Thai Embassy, Washington D.C., 2022). The BCG economy is key to developing Thailand's bio-production and waste management systems within the concept of sustainable development and global CO_2 reduction. The greatest economic impact relates to the use of agricultural products and their waste and to eco-tourism.

Thailand's 12th National Economic and Social Development Plan cycle (2017–2021) focused on 3 areas: economic, environmental and social development. The BCG economy is one of the strategic initiatives in the current 2021–2026 cycle. Industry will be encouraged to develop waste management systems and environmental product responsibility while the Thai people will be encouraged to be aware of the environmental effects of their consumption. The challenge is how to imbed BCG plans into good practice in Thailand. Both governmental and private sectors will need to act to accelerate the growth of such activity. Financial support, expertise and co-ordination are all important to drive this forward. Even though the country is still feeling the effects of the Covid-19 pandemic and other international factors that suppress the economy, it, like all countries, must not delay such actions. A BCG economy approach can be applied both to local communities and business in Thailand and to global networks to meet the economic goals of the future in a sustainable way. Therefore, BCG models in other countries will be also be investigated in this review to compare the different approaches.

Materials and Methods

The concept of the (bio)circular economic model and how it can be used to support a sustainable economy is reviewed. Bio-Circular green (BCG) economy plans are examined in the light of how Thailand and other countries are developing their policy and the approaches compared. In particular the circular economy model focusing on bioenergy and its application is investigated. Data was collected from literature reviews, books, journals, conference publications, websites etc. The data were screened and verified using governmental and international conference proceedings, governmental publications on policy development, strategic processes and project planning. Impacts are analysed by SWOT analysis of the economic, environmental and energy areas of a BCG economy. The results inform the conclusions, recommendations on policy, research and development (R&D) and future work.

Results

Policy and planning of Circular Green Economic models in Thailand and other countries

Thailand

In Thailand, modelling of a circular economy focusses on bio-based products in a green economy known as the "Bio-Circular Green Economy (BCG) Model" due to Thailand having abundant agricultural resources and, currently, much remaining waste bio-material. BCG has been introduced as a challenging economic model for the future development of the country. The BCG model is addressed as part of "the national agenda" to develop sustainable growth by taking advantage of Thailand's biological and cultural diversity, technology and innovation. An action plan sets out to holistically transform land management, food security, health and industrial systems and achieve the goals of sustainability and well-being (Department of Alternative Energy Development and Efficiency, 2018; APEC, 2022). The Thai Government has adopted the BCG model for its economic development plan of 2021–2026 with the aim of increasing GDP by THB 1 trillion within the next five years and to support 20 million jobs in four targeted sectors: (1) food and agriculture; (2) medical and wellness; (3) bioenergy, biomaterials and biochemicals and (4) tourism and the creative economy (Meiksin, 2020).

To achieve this goal, the Thai Minister of Higher Education, Science, Research and Innovation has said "new knowledge and technology must be used to add more value to more products from various sectors, including food and beverage manufacturing, medicine, energy, bio-chemicals and tourism" (National Science Technology and Innovation Policy Office, 2021a). The plan includes renewable and biological resources and the conversion of waste streams into value-added products, such as food, bio-based products, and bioenergy (Bioeconomic Research Community Circular Economy and Green Economy, 2018). Drivers that have been put in place to motivate strategic action are in the following areas: (1) building sustainable natural resources and biodiversity; (2) developing the local economy and (3) enhancing a sustainable BCG model in industry (Table 1).

The implementation plan addresses the time-lines of work and goals in each phase, as shown in Table 2.

The BCG committee structure in Thailand

To monitor and control development within the plan in Thailand, a national BCG working group was formed which includes: 1) a BCG Policy Board of Directors; 2) a BCG Economic Promotion Agency and 3) a BCG Economic Promotion Agency subcommittee. Their approach covers: (1) initial R&D development; (2) industrial development; (3) creating new industrial sectors; (4) encouraging BCG start-ups; (5) area-based development; (6) regulatory frameworks; (7) infrastructure; (8) global networking and (9) talent and entrepreneur development.

Activity of the Board of Investment (BOI) in Thailand

The Thailand Board of Investment, helps to support and promote the BCG economy initiative (Thailand Board of Investment, 2019). There is an 8-year incentive scheme covering areas such as cooperate income tax (CIT) and exemption of import duties on machinery and raw materials as shown in Table 3 (Kaewsang, 2020).

Table 1 Policy and planning of the Bio-Circular-Green (BCG) model in Thailand

Plan 1 Building the sustainability of natural resources and biodiversity	Plan 2 Strengthening local economy	Plan 3 Enhance sustainable BCG at the industrial level
- Conserve, restore, manage, utilise and increase biodiversity and cultural diversity	- Increase food production and quality, good health and energy security	- Develop target sectors
- Resource management	- Area-based development	- Talent & entrepreneur development
- Develop resource management systems	- Increase accessibility of information and knowledge transfer to the community	- Build and develop markets - Facility and Infrastructure development

Table 2 Bio-Circular Green (BCG) Economy development in each phase

Phase I (2021–2022)	Phase II (2023–2025)	Phase III (2026–2027)
1. Create awareness and understanding about the BCG economy	1. Develop quick win projects	1. Push target products and services to the international market
2. Gather information and create national databases such as in biodiversity, cultural diversity and tourist attractions	2. Expand project area, Develop new products and services. Create/develop innovative entrepreneurs	2. Expand sustainable production and consumption systems
3. Gather successful cases as case studies	3. Push target products and services to the market	3. Encourage Thailand as key player in setting standard for BCG products and services globally
4. Set and develop laws and regulations	4. Develop a domestic market for BCG products and services	4. Invest for frontier infrastructure
5. Develop infrastructure and capacity building	5. Initiate new industrial sectors	
6. Start "quick-win" projects	6. Drive proposals based on policies related to BCG	
7. Develop policy related to BCG, such as the reduction of single-use plastics and reductions in chemical and antibiotic use in plants and animals (Projects should be "bottom-up")		
8. Develop sustainable ecosystems through financial support and involving specialists from other countries		

Table 3 Thailand Board of Investment support for investment in Thailand (Kaewsang, 2020)

8 y.	Category	Incentives	Exemption CIT	Exemption of import duties on machinery	Exemption of import duties on raw material	Non-tax incentives
	A1	Knowledge-based activities focusing on R&D and design to enhance the country's competitiveness	8 + merit years (no cap)	/	/	/
	A2	Infrastructure activities for the country's development: activities using technology to create value-added products with no or very little existing investment in Thailand	8 + merit years (no cap)	/	/	/
	A3	High technology activities which are important to the development of the country	5 + merit years (no cap)	/	/	/
0 y	A4	Activities with lower technology than A1-A3 but which add value to domestic resource and strengthen the supply chain	3 + merit years (no cap)	/	/	/
	B1	Supporting industry that does not use high technology, but is still important to the value chain	- + merit years	/	/	/
	B2	Supporting industry that does not use high technology, but is still important to the value chain	Year	-	/	/

Example of a Bio-based circular model for bioenergy in Thailand

Bio-based products are products extracted from natural raw materials. They tend to be environmentally friendly and have high market demand. Many bio-based products can replace petroleum-based products. For example, Thailand produces biofuel from molasses, cassava, palm oil and other biomass. Biofuels (liquid, solid and gaseous) can be used to provide renewable energy to help replace fossil fuels. Thailand has an alternative energy development plan (AEDP-2018) for these biofuels. In addition, they have other natural resources to produce energy, for example, PV solar, and wind. All have to be integrated into the energy supply system (Department of Alternative Energy Development and Efficiency, 2020).

The BCG approach also provides an opportunity for Thailand to add high value bio-products into existing product ranges using the waste from bioenergy production. For example, bagasse, already used to produce food cartons etc., could produce a range of "value-added" compounds for use in cosmetics and food production. Thus a "waste" becomes a raw material and its value rises from THB 1/kg to an estimated THB 260/kg. If this bagasse can be used to produce medically active compounds the value would increase to THB 1,000/kg (Office of the Ministry of Higher Education, Science, Research and Innovation, 2019). Bagasse and the residue from cassava and palm oil can also be used as precursor materials in the production of bio-plastics (Thailand Board of Investment, 2019).

Palm oil is used in biodiesel production. The R&D model suggests that the remaining oil palm bunches and leaves can be turned into bioenergy or new products (Department of Alternative Energy Development and Efficiency, 2020). Furthermore, the waste-water can be used to produce biogas for electricity generation and CO_2 emissions can be used to enhance the growth of algae or other plants (Department of Alternative Energy Development and Efficiency, 2020). Options for re-shaping traditional energy sectors include: biomass power plants, bio-refinery power plants and combined bio-hydro power plants (Kaewsang, 2020).

For investment and R&D into biotechnology projects (Table 4), the BOI has focused on bioenergy such as fuel from waste recycling and waste agricultural products, with other projects looking at producing biomaterials and high value-added compounds from biomass/agro-based materials. The Covid-19 pandemic is an indicator of how biomass products can be rapidly repurposed to deal with changing circumstances, so bio-ethanol stock can quickly be re-purposed as sanitizing hand gel, alcohol spray and other anti-viral systems.

Table 4 Investment intensive BCG industry sectors (Kaewsang, 2020)

Category	Bioenergy and Biofuels	Biotechnology R&D	Waste and recycling	Eco-friendly chemicals/polymers
A1 8y CIT exemption (no cap)	Electricity or electricity and steam from garbage or refuse derived fuel	activity in manufacturing using biotechnology. Raw materials and/or essential materials for molecular biotechnology R&D. Biological substance analysis and/or relevant other activities	-	-
A2 8y CIT exemption	Electricity or electricity and steam from renewable energy. Fuel from agricultural products. Fuel from agricultural scrap or garbage or waste	-	Waste treatment or disposal	Eco-friendly chemicals or polymer, or manufacture of products from eco-friendly chemicals or polymers
A3 5y CIT exemption	Biomass briquettes and pellets	-	Recycling and reuse of unwanted materials	Products from eco-friendly polymers

Case study of BCG model in Thailand

As a case study of the BCG model development in Thailand, transportation changes were considered, moving from the internal combustion engine to electric vehicles to reduce future fossil fuel usage. This transition may affect the biofuel (derived from palm oil) supply chain as well as reducing crude oil refinery output and the need to remodel pumping (gas) stations. A study of a BCG model for palm oil production in Thailand by the Kasetsart Agricultural and Agro-Industrial Product Improvement Institute and the Department of Alternative Energy Development and Efficiency looked at alternative uses for the oil palm including the use of palm oil in added-value by-products and how to use biogas from the processing to produce electricity, as well as clarifying the CO_2 generated from palm oil production for each component (Department of Alternative Energy Development and Efficiency, 2020)

Existing knowledge in universities in Thailand can support the BCG model. For example, agricultural planting, harvesting technology, biotechnology, chemical processes, biochemical engineering, chemical production, bioenergy (biomass, biogas, biorefinery and renewable energy), can all be applied to change palm oil waste residues and by-products to produce bioenergy, such as biogas and biomass materials to generate electricity. In addition, some parts of the palm oil tree, leaves and empty fruit-bunch, can produce animal feed, soap, pharmaceuticals, cosmetics, oleochemicals, bio-based oils, bio-lubricants, bioplastics, biojet fuel and bio-rubber (Department of Alternative Energy Development and Efficiency, 2020).

China

Moves towards a circular economy in China began with an idea of a circular economy officially adopted in 2002 (Geng and Doberstein, 2008). China has abundant natural resources from a global perspective, such as 46% of aluminum, 50% of steel and 60% of cement production of the world, all of which can be recovered, reused or recycled. China now has at least three plans relating to the circular economy: (1) legislation for the promotion of the circular economy; (2) the Circular Economy Development Strategies Action Plan and (3) the 12–14th Five Year Plan (National Congress of the Communist Party of China, 2002; Yuan and Moriguichi, 2006; Geng and Doberstein, 2008).

At its National Congress in 2002, China also launched a policy aimed at establishing more sustainable practice alongside economic growth (National Congress of the Communist Party of China, 2002). This policy includes the promotion of environmental management systems (EMS), eco-design and cleaner production using lifecycle analysis (LCA) and material flow analysis (MFA) to reduce CO_2 emissions. The plan aims to reduce waste and address social issues related to the production and consumption of products.

The legislation for the promotion of the circular economy of August 2008

The State Council is responsible for the promotion of the circular economy. Under the legislation, any new governmental industrial policies must meet the criteria for promoting a circular economy. Industries must ensure that their management systems reduce resource consumption and waste generation and must improve resource recovery and recycling. The Chinese government encourages R&D and international cooperation in these areas. They support education and dissemination of

scientific knowledge aiming to empower citizens to conserve natural resources and protect the environment (Standing Committee of the National People's Congress, 2008).

The Chinese 5 year plans

In relation to the environment and circular economy, the 12th 5-year plan (2011–2015) focused on the efficient use and recycling of heavy industrial resources. Following the plan, China created around 1,000 industrial parks and is promoting an economic growth pattern based on renewable energy and towards zero emissions of pollutants. In the 13th 5-year plan (2016–2020), the Chinese government refined their strategic plan for resources to promote increasing resource efficiency, supporting green initiatives and further reducing waste. The emphasis was on improving water resource quality, preventing soil pollution, promoting green materials and introducing a new environmental protection tax (China Water Risk, 2016). The National Development and Reform Commission (NDRC) released the 14th plan (2021–2025) on 7th July 2021, including a blueprint for circular economy development to improve recycling, resource utilization, efficiency and clean production in key industries, including petrochemicals (Yunfeng, 2021).

By 2050, it is intended that recyclable production in China will be fully implemented. Green design and clean production will be promoted. Resource utilization efficiency will be improved. The replacement rate of primary resources by renewable resources will be further increased. Productivity is aimed to be increased by about 20% compared with 2020, while energy and water consumption will be reduced by 13.5% and 16%, respectively. Areas such as crop stalk utilization will be above 86%. Bulk solid and construction waste recycling is set to reach 60%. Sixty million tonnes of wastepaper and 320 million tonnes of scrap steel will be recycled, while the output of recycled non-ferrous metals is expected to be 20 million tonnes. The NDRC intends to boost clean production in key industries by making policies specific to petrochemicals, chemicals, coking, cement and nonferrous metals. It will promote recycling development in industrial parks. Waste and heat gradients will be used to produce energy, while water resources will be recycled (Yunfeng, 2021).

The circular economies development strategy action plan

This action plan, established on January 23, 2013, outlined three levels of circular economy in China: companies, industrial parks, and cities or regions. The focus was on both the industrial and social sectors with embedded resource recycling technologies. The first circular biofuel project started in September 2019. With ERASMUS (an EU program) support, the project aims to develop a problem-solving attitude in students studying the bio-based economic sector at universities (Nibbi et al., 2019). For developing a circular economy on biofuel, China also has developed the Guigang Eco-Industrial Park in the Guangxi Zhuang Autonomous Region, where a circular approach to sugar production is being developed. The demonstration park has a cane field system, sugar system, alcohol system and a papermaking system, along with combined heat and power (CHP) and integrated environmental treatment systems. The production optimizes resources and waste utilization and reduces environmental pollution. The systems of industry and farming are thus closely combined, as shown in Fig. 1.

European Union and other countries

The European Commission strongly supports the development of a circular economy and bioeconomy at both the national and regional levels (Kovacic et al., 2019). The EU bioeconomy is made up of several inter-related concepts, such as the bio-based economy, the green economy, and the circular economy (Kardung et al., 2021). The first circular economy package consisted of the action plan and proposals for waste legislation in 2015. In 2017, the circular economy objective and actions were further clarified in "the Paijat-Hame Roadmap - Towards a Circular Economy" with the vision of Paijat-Hame in Finland being a successful resource-efficient region by 2030 (European Regional Development Fund, 2019). This involved a co-operation among regional stakeholders of the Paijat-Hame Circular Economy Cooperation Group which consists of representatives of the region public authorities, academia and businesses. Five themes were specified in a regional roadmap: (1) sustainable businesses in the bio circular economy; (2) new consumption models and business opportunities; (3) closed loops of technical streams; (4) moving towards energy self-sufficiency and (5) piloting and demonstrating innovative solutions.

In 2018, the regional circular economy roadmap was updated. As a central part of the update, the bio-based circular economy actions were listed as: making a bio-based circular economy action plan, developing separate collection and composting of bio-waste, closing nutrient cycles, and encouraging new innovative bioproducts and bioenergy.

Revised Waste and Packing Directives were published in 2018 to meet the current environmental, social and economic challenges. It was to be implemented by all Member States by June 2020.

EU financial support: The EU has funded the early stages of circular bioeconomy development. Companies can use funding for innovation of their activities to reach new markets. The funding specifically invests in: (1) circular/bio-economy technologies; (2) biomass/feed stock production that boosts agricultural productivity while lowering environment impact; (3) biomass/feed stock technologies that result in higher-value green goods; (4) bio-based chemicals and materials and (5) biological alternatives in fields such as cosmetics. An example of how this funding is applied is "BIOREGIO - Laying a Cornerstone for Action Plans". BIOREGIO (2017–2021) aimed to boost a regional bio-based circular economy through a transfer of expertise about best available technologies and cooperation models (BIOREGIO Interreg Europe, 2019).

The UK

The UK is using a circular economy approach to accelerate the transition to a bioeconomy that is climate neutral, inclusive and prospers in harmony with nature (Palahí et al., 2020). The activities include: (1) raising awareness and inspiring action towards a circular bioeconomy: from nature-based solutions to reimaging cities; (2) catalyzing investment and connecting investors to companies for start-up and scale-up projects to bring the circular bioeconomy from "niche to norm"; (3) supporting governments to develop science-informed strategies to transition towards a circular bioeconomy; (4) demonstrating the potential of the circular bioeconomy through pilot projects and training modules and (5) accelerating land restoration initiatives.

The circular bioeconomy is intended to be powered by renewable energy and includes and interlinks the following systems and sectors: (1) land and marine ecosystems, green infrastructures and the services they provide in cities; (2) primary production sectors (agriculture, forestry, fisheries, aquaculture and aquaponics) and (3) economic and industrial sectors relying on biological resources and nature-based solutions (food, wood industry, bulk and specialty chemicals, construction, packaging, textiles, pharmaceuticals, bioenergy, all sectors benefiting from bio-based solutions or ecosystem services such as nature tourism, water supply, biomass and bioprocessing; bioproducts, pharmaceuticals, bioenergy and sustainable biofuel. This all relates to renewable natural capital, biodiversity, "biocities", social prosperity, and wellbeing (Palahi, 2021).

Denmark

From the 31st May to the 2nd June 2021, at the Royal Thai Embassy in Copenhagen, Thailand's National Science and Technology Development Agency and the BOI organized a webinar. This enabled Thailand and Denmark to exchange experience between businesses in both countries (National Science and Technology Development Agency, 2021b).

Denmark intends to transit to a green energy society. They have set goals as follows: (1) reduce greenhouse gases (GHGs) by 70% by 2030 (compared to 1990); (2) reduce pollution by 50–54% in 2025 (compared to 40% in 2019); (3) make water quality improvements and improve the use of waste and (4), strengthen public-private partnerships in mitigating climate change (Organization for Economic Co-operation and Development, 2021; State of Green, 2022). Denmark's strategies to develop a circular green economy include: (1) capacity building of bio-circular skills; (2) collection and analysis of information; (3) developing standards; (4) changing patterns of consumption; (5) creating a market to reduce and recycle waste and (6) creating added value to biomass raw materials. The plan focuses on waste prevention from the production processes and coexistence of industry and communities. The plan also includes soil quality improvement, recycling and reusing waste and the construction of sufficient incinerators (National Science and Technology Development Agency, 2021a).

Finland

In Finland, in 2014, the Bioeconomy Strategy was issued with a vision of sustainable solutions for the bioeconomy to be the basis of Finland's well-being and competitiveness. The Finnish Road Map to a Circular Economy 2016–2025 was published in 2016 (Sitra, 2016). It was the world's first national circular economy roadmap and described actions for Finland to become a pioneer in the circular economy (Orola, 2018). In 2019, an update of the roadmap was published (Finland's Road Map to The Circular Economy 2.0). An action plan set the future steps in the Paijat-Hame region in southern Finland (see under "EU" above). It introduced a circular economy model of biological resources to manage a sustainable economy and to add social and ecological value to products (Medkova and Vanhamaki, 2018). It includes both short-term and long-term targets. The programme began in 2021. The actions and timeframe are listed in Table 5.

Table 5 Finnish example of action plans for circular economy development with timeframe (Medkova and Vanhamaki, 2018)

Long-term goal	ERDF Programme	ERDF programming period 2014–2020	Long-term goal
- Developing a sustainable bio-based circular economy enhancing the circulation of nutrients	- New solutions in collection and utilization of biowaste	- Developing utilization of bio-products and bioenergy	- Developing Paijat-Hame regional circular economy strategy
- Promoting utilization of bio-based materials and regional bio-based circular economies	- Reducing amounts of biowaste and wasted food	- New possibilities for utilizing wastewater sludge	-Sharing good practice of implementing "Smart Specialisation" spearheaded through a road map
- Aiming toward closing nutrient loop of nitrogen and phosphorus	- User-oriented development	- Material utilization, developing and further processing by–products	-Involving sustainability in bioeconomy, developing holistic circular economy perspectives
- Developing sustainable business models in the bio-based circular economy	- Testing pilot solutions e.g. developing bio-waste bins, composting pilots	- Utilizing by–products in small scale combined heat and power systems (related to BIOREGIO Good Practice "Use of organic residue for energy production")	-Continuous updating in cooperation with the circular economy working group
		- Developing the use of biogas drive vehicle	- New ways of involving companies in the process.

The Paijat-Hame Regional Council steered the drafting of the action plan and, together with Lahti University of Applied Sciences (LAMK), participated in the writing process. Both LAMK and the Council are BIOREGIO project partners and LAMK acts as a lead partner. The action plan was approved in May 2019 (Soini-Salomaa, 2019). The Paijat-Hame Bio-based Circular Economy Action Plan's implementation will be followed up by the Paijat-Hame Circular Economy Cooperation Group and the BIOREGIO project. At the same time, the group is committed to update the earlier-mentioned Paijat-Hame Roadmap "Towards Circular Economy" (European Regional Development Fund, 2019). The action plan is shown in Table 6.

Collaboration between the EU and Thailand

The EU and Thailand have addressed the BCG model in a cooperative venture. The EU has placed the "European Green Deal" at the heart of its policies ("an opportunity to improve the health and wellbeing of people by transforming our economic model") (European Commission, 2019). The EU has already adopted a circular economy package covering the whole cycle (production, consumption, waste management and secondary raw materials). For the past two years, the EU invested close to EUR 1 billion (THB 33 billion) into research and innovation as well as financing projects and initiatives to support this strategy (Meiksin, 2020). The National Science and

Table 6 Action plan of Paijat-Hame bio-based circular economy

	Action plan
Action 1	Promoting a sustainable bio-based circular economy and enhancing nutrient cycles. Establishing agricultural, biochar and wastewater sludge pilot projects. The themes include the following:
	1) development of the circularity of wastewater sludge and biowaste side streams from biogas processes to new products.
	2) promotion of biogas side streams and bio-based circular economy in agricultural nutrient cycles.
	3) willow cultivation for biochar and experimentation of pyrolysis along with life cycle assessment of the mentioned processes.
	4) creation of a platform for regional nutrient trading
Action 2	Pilot projects for biowaste collection and recovery: It focuses on promoting a separate collection of biowaste in residential areas with single –family homes. It includes testing different options (shared bins, regional collection, composting and co-composting), as well as conducing life-cycle assessment. In addition, it is raising the awareness of residents to reduce the amount of biowaste through a user-oriented approach.
Action 3	Promoting the use of bio-products and bioenergy: Together with companies, industrial symbiosis and opportunities for developing bio-based products are promoted (e.g. bioplastics). The action comprises the development of piloting and testing environments for bio-based materials (e.g. pyrolysis and digestion and exploring novel small-scale bioenergy solutions). Industrial symbiosis (e.g. to close CO_2 cycles) and development of new products from bio-based side-streams are promoted. In addition, the regional climate change mitigation roadmap is drafted in the region.
Action 4	Paijat-Hame to be an international reference area for circular economy: The last action follows from the other three as it underlines the strategic development of the circular economy at the regional level. It includes dissemination of new solutions and good practices in the region, as well as internationally, and strengthening the expertise of the circular economy in co-operation with universities and companies.

Technology Development Agency has a research programme and infrastructure that supports BCG, including progressing the construction of the Eastern Economic Corridor of Innovation (EEC) to serve as Thailand's new growth hub. It will house state-of-the-art essential facilities for bio-industry development such as factories, phenomics, specialty greenhouse systems, and biorefinery pilot plant as well as advanced infrastructure such as a "Demo Factory and Industry 4.0 Testbed", (fourth generation synchrotron facility), a high performance computing facility, autonomous vehicle testing and a "living laboratory". The EU and Thailand meet to discuss progress and share opportunities to develop the circular economy (Meiksin, 2020).

Discussion of Thailand's policy in comparison with other countries

Thailand, China, the EU and other countries have similar concepts to reduce, reuse and recycle waste. They are looking to develop new circular economies by using trading, marketing, new innovative products and new technologies, removing waste from production and recycling and looking towards zero waste (the "zero emissions enterprise"). In addition, they have a willingness to remind both producers and consumers to be concerned about the fate of their goods or products after use. They are supporting projects in R&D, education and demonstration plants. In addition, they provide funding for subsidies and tax exemptions for the implementation of strategic plans. Through these actions, they aim to reduce CO_2 and other GHG emissions, following the guidelines agreed internationally to reduce the effects of climate change.

China is currently concentrating on element material recycling and reuse by industry. This has multiple benefits of reducing the demand of scarce elements from raw materials (and hence ever more destructive mining operations), reducing waste entering the ecosystem and improving the economic life-cycle of the products. There are bioenergy-based circular economy demonstrations in China based on industrial waste reduction.

In Thailand, the current emphasis is on the wider uses of biofuel while in the EU the concerns are about agricultural waste, recycling waste for energy, and green production.

In Thailand and the EU there are differences in terminology and the understanding of various terms when discussing the circular economy. For example, the EU talks of a "circular economy" while Thailand focuses on the "bio-circular economy". However, both aim to create a national agenda for a circular economy; the concepts are similar as are the aims to develop new markets and encourage sustainable economic development. Thus, it is important that there is joint effort towards an agreed nomenclature to progress international collaboration. Countries have similar ambitions in circular economy policy and planning, but there are different specific applications and time-lines. Most start by focusing on waste and biodegradation. Vanhamaki et al. (2019) has provided an overview of the national strategies and comparisons between countries are given in Table 7.

Table 7 Thai bio-based circular economy strategy compared with other countries

National level	Thailand	China	Finland	Spain	Slovakia	Greece	Romania	France
National strategy name	National agenda on BCG Model	Legislate for Promotion of circular economy	The Finnish Road-map to a Circular Economy	Waste Management State Plan -PEMAR	The Waste Management Program of Slovak Republic	National Plan for Waste Management	National Waste Management Strategy	Legislate Relative to Energy Transition for Green Growth
Valid period	2021–2026	2021–2025	2016–2025	2016–2022	2016–2020	2015–2020	2014–2020	2015–2030
Circular economy included?	Yes	Yes	Yes	Yes	Yes	No	Yes	Yes
If no, specify other corresponding terms	Increasing bioproducts, recycling biowaste	Raw material industry recycling reuse			Recycling, biowaste disposal avoidance			
Biobased circular economy included?	Yes	Yes	Yes	No	No	No	No	No
Circularity of nutrients mentioned?	Yes Recycling of biodegradable waste, biochemical products supplement biopharma	-	Yes Sustainable food systems, closing to loop	Yes Collecting and processing biowaste	Yes Recycling, biodegradable waste	Yes Separate collection and management of biowaste introduced	Yes Circulation of organic waste fractions	Yes Reducing food waste, separate collection of biowaste
Status for new National Clean Energy Strategies	Thailand Bio-Circular Economy Roadmap (2021–2026)	Chinese 14th five year plan (2021–2025)	Existing (2016)	Circular Spain 2030: Spanish Strategy for Circular Economy	Greener Slovakia-Strategy of the Environmental Policy of the Slovak Republic until 2030	Greek National Circular Economy Plan	Romania A circular Economy platform	French National Circular Economy Roadmap

The results of applying a SWOT analysis to the impacts of implementing a BCG economic model on Thailand's economic, environmental and energy systems are shown in Table 8.

The GDP value of the energy, materials and biochemistry sectors totals about THB 9.5 million billion (Office of the National Economic and Social Development Board, 2016) There is high growth potential to increase the renewable energy (RE) share of the energy sector to 30% and to create added-value through the development of highly efficient energy production innovations that can accommodate a wide range of waste types (industrial, household and agricultural). Wastes are thus resources that can be recycled and this can lead to the creation of community-based biomass resource hubs. Solar floating or solar rooftops can generate income by selling electricity to the microgrid/smart grid system using block chain technology as a management platform. However, it is necessary to develop the technology and energy storage systems to ensure the stability of these mixed source power grids. In terms of materials and biochemicals, there is potential for further development of agricultural materials into high-value added chemical and bio-material products such as bioplastics, fibers and pharmaceuticals. The above approaches have the potential to add more than THB 260 billion in GDP.

Table 8 Analysis of the impact of a BCG economy on Thailand's economic, environmental and energy systems

Strengths	Weaknesses
1. Economic - A BCG model will assist in adding value to bioindustry products, biorefinery operations, green goods and recycling waste, - Reduce social and economic inequality and the gap in income between industry and farmers by increasing income for farmers and farming communities, - Enhancing level of Thai food industry operators, - increasing world's top-5 health food and high-value ingredient producers, - Enhancing pharmaceutical production and medical devices, - Thailand has access to the Eastern Economic Corridor which is a new economic area to support biochemical production. 2. Environment - Bioeconomics as a tool to develop SDGs which reduce GHG_S, CO_2 and climate change problems, - Eco-Tourism management systems can enhance the Top 3 position in the Asia Pacific region (Travel & Tourism, World Economic Forum), - Bioproduction helps to achieve carbon neutrality goals and net zero, - BCG enables CO_2 reduction from circular economy and can achieve modal shifts in logistics and efficiency, - BCG model can activate public awareness on Climate change and environmental problems. 3. Energy and other products - Bio-industry (bioenergy and biomaterials) can increase GDP. They have the potential to improve energy efficiency and increase exports, - Increase new technology and develop professional skills, - Innovation deploys decarbonization technology and carbon neutrality across all sectors (electricity, biomass, bioenergy technology, carbon capture, green H_2 fuel cells).	- Thailand needs highly skilled employees with high income. - Biomaterials can be difficult to gather from the farm source. - Agricultural raw materials and products are susceptible to climate change and seasonal change such as flooding and drought. There is a need to ensure that feedstocks can reach biofactories on time and in the required quantity and quality - Developing a BCG model needs many experts to develop and process bioproducts, renewable energy, circular waste to energy and other green businesses. - Legislation and regulations must adapt to support the required innovations. - A local manufacturing base for production of bioreactors and other new machinery and processes is required to reduce reliance on imports - R&D needs to support BCG model on energy issues.
Opportunities	**Threats**
- Thailand has a large agri-industry which has potential to develop new and innovative goods. These can increase GDP. - Sustainable development goal (SDG) philosophy can be imbedded in policy and planning to develop the country. BCG is a part of the sustainable development goals. - Thailand has fundamental knowledge and background in biochemicals, waste recycling processes and bioenergy and has the potential to develop this technology in the future. - It is a good time to combine information technology platforms to connect bioenergy products and markets.	- Biochemical technology needs funding or financial support as the investment required can be high. - Bioenergy & biopetrochemical/ biorefinery, and bioplastics production are complicated processes that need biochemical engineers /experts and professional technicians to run the projects. - Biocatalysts are expensive. They currently need to be imported from other countries which endangers supply.

At the regional level, in 2021 ASEAN adopted the Framework for Circular Economy for the ASEAN Economic Community (AEC) at the 20th AEC Council Meeting. They selected five strategic priorities: (1) the standards of circular products and services; (2) trade openness and trade facilitation in circular goods and services; (3) enhanced role of innovation and digitization in emerging/green technologies; (4) competitive sustainable finance and innovative investments and (5) efficient use of energy and other resources (Economic Research Institute for ASEAN and East Asia, 2021). In Nov 2022, Thailand was host to the APEC meeting. At this meeting, economic recovery and the concept "Open. Connect. Balance" was promoted. Thailand foresees ways to increase trade and investment through socially responsible business operations with an emphasis on balance rather than profit. The concept of the bio-circular green economy was supported by 21 member countries around the region (Thailand Convention and Exhibition Bureau, 2022)

Conclusions, recommendations and future trends

Conclusions

Thailand, as are many countries, is moving toward a circular economy and sustainable development. The elimination of waste and the use of renewable resources are important for future consumption and the wellbeing of the country and of the planet. The BCG Economy Action Plan is a good example of creating innovation to drive the economy into a future "new normal" environment. Thailand has a policy to develop a "BCG model strategic plan, 2021–2026" that will focus on four industrial sectors: (1) food and agriculture; (2) medical and wellness; (3) bioenergy, biomaterials and biochemicals and (4) tourism and the creative economy. This process involves three phases. The first was 2021–2022 focusing on understanding the BCG model and starting "quick-win" projects. In the second (2023–2025), the government will develop the domestic market and new innovative industries. The final phase (2026–2027) will concentrate on production and consumption systems, global interactions and infrastructure. The BOI provides financial incentives for 8yrs. The implementation of policy and planning needs concrete projects, suitable initial funding, industry incentives and time; with perhaps time being in the shortest supply.

Recommendations on policy

Action and activity toward a more sustainable future should plan and share good practice. Enhancing networking between countries and regions benefits communities, citizens, the public and private sectors and helps to create income. Furthermore, R&D projects should be capable of pushing forward regional, national and global goals. A BCG action plan should be holistic in its approach and relevant to all sectors and operational at all levels (international, national, regional and local). It should look forward step-by-step in its implementation and be adaptable to include best practice and innovations. It must be driven to make the policy and planning become real. It should have projects to support future development. The implementation mechanism must provide a budget and expertise to meet milestones and goals. Evaluation of projects, the recognition of good practice and follow on from R&D are all important. Participants and stakeholders must develop good communication channels both more widely and in local communities. Such major and far-reaching changes need the participation of the leaders in other sectors such as industry and agriculture, politicians, legal experts and regulators.

BCG includes the bioeconomy, circular economy and green economy. The concepts can be applied widely to bio-based products. Implementation will be different in different countries because the bio-based products will be different. However, governmental organizations must support each other both nationally and internationally to build and maintain momentum. They can share information, exchange expertise and create and co-operate in future markets. Finally, any bio-circular economy action plan must be resilient to shorter term external factors such as the Covid-19 pandemic. Such factors affect not only the Thai economy, but also the world economy and it would be easy for countries to shelve longer-term goals to concentrate on shorter term problems. But building a sustainable economy cannot be delayed.

Recommendation on research context in the future (or future trends)

There are many technological developments to reduce fossil fuel usage through using clean technology, bioenergy or renewably sourced electricity. Thailand has educational facilities and an existing background in the agricultural sector. Therefore, Thai research should concentrate on bioproducts, biochemical processes, biocatalysts and bioenergy such as bioethanol, biodiesel and bio-based oil for transportation. R&D can be applied to bio-petrochemicals, bioproducts, biorefineries, biofertilizers, biojet and other sustainable aviation fuels, oleochemicals, re-using cellulose paper, waste to energy,

biomass CHP, bio-lubricants, bio-based oil, bioplastics, bio-rubber, H_2 green fuel cells and synthetic biofuel. The BCG model can be applied to and incorporate CO_2 mitigation, LCA, carbon foot-printing and carbon capture utilization and storage. Information Technology will need to be developed for bio-production, light-weight technology and bioproducts. R&D must be encouraged, while commercial scale-up will depend on the investment costs and local and global potential markets.

Conflict of Interest

The authors declare that there are no conflicts of interest.

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