

Article

A Comparative Analysis of Circular Economy Practices in Saudi Arabia

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Abstract: The rise in urbanisation and resource consumption has highlighted the urgent need for sustainable economic models. The traditional linear economy, which relies heavily on non-renewable resources, exceeds the Earth's capacity and poses significant sustainability challenges. As a result, there is an increasing necessity to transition towards a circular economy (CE) as a more sustainable alternative. Saudi Arabia, one of the world's largest economies, is striving to implement this shift due to considerable environmental and economic challenges. However, the country currently lacks a dedicated circular economy strategy, which hinders its efforts to address issues such as waste management and excessive consumption. To bridge this gap, a comprehensive framework was developed to assess and compare Saudi Arabia's circular economy initiatives, strategies, and policies with those of China, Japan, and Europe. Data were collected and analysed using thematic analysis, allowing for the identification of key similarities and differences between these regions. The study revealed notable variations in policies and practices, highlighting best practices that Saudi Arabia could adopt to strengthen its sustainability efforts. The findings underscore the importance of incorporating global best practices while tailoring strategies to the Kingdom's specific needs. Policymakers and researchers in Saudi Arabia can utilise these insights to support a more effective transition towards a circular economy. Future research could adopt a quantitative approach, using indicators and metrics to enhance the impact of these findings.



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1. Introduction

During the last few decades, economic growth has brought significant environmental challenges. Human activities have accelerated climate change, reducing the ability of natural ecosystems to support life. As consumption increases, the ecological footprint of humans expands, resulting in more significant ecological deficits worldwide [1]. Therefore, the concept of sustainability has gained prominence emphasising the preservation of natural resources to ensure their long-term availability [2].

Saudi Arabia, the largest economy in the Middle East and North Africa, is recognised for its substantial economic output and high GDP growth [3], with an area of 2,149,690 km² [4] and a population of 32.17 million as of 2024 [5]. Saudi Arabia is also a member of the Group of Twenty (G20), which highlights its position as a leading global economy [3]. Rapid population growth and urbanisation in Saudi Arabia have contributed to increased waste generation [6]. Furthermore, Almulhim & Al-Saidi [7] point out that

Saudi Arabia's rapid economic growth and strong reliance on fossil fuels have led to a significant rise in energy consumption and CO₂ emissions, leaving the country vulnerable to climate change impacts [8]. Over the past 40 years, Saudi Arabia has seen considerable industrial expansion, adversely impacting environmental quality [9] suggesting that the current economic model lacks sustainability [8].

Saudi Arabia produces approximately 14 million tonnes of municipal solid waste (MSW) annually, averaging around 1.4 kg per person per day [6]. This rate far exceeds the regional average of 0.81 kg and the global average of 0.74 kg [8]. Waste disposal in Saudi Arabia predominantly relies on landfills, which handle about 85% of all waste treatment. In contrast, only about 40% of waste in Organisation for Economic Co-operation and Development (OECD) countries is disposed of in landfills [10]. Recycling in Saudi Arabia is limited, with less than 15% of collected MSW being recycled. Informal recycling is carried out by scavengers, who manually extract materials like paper, metals, and plastics [6]. This results in a low overall recycling rate. Adopting a circular economy (CE) in Saudi Arabia is crucial, particularly in addressing food waste, which poses a serious threat to food security. Research by [11] highlights that Saudi Arabia has the highest per capita food waste rate among G20 nations, as reported by the 2021 Food Sustainability Index [8].

Saudi Arabia's plan for developing new cities and advancing infrastructure and real estate projects, has also led to a substantial increase in construction and demolition waste (CDW), especially in major cities such as Riyadh, Dammam, and Jeddah. New construction projects generate 50–60 tons of waste per 1000 m², while demolishing old buildings produces 700–1200 tons of waste per 1000 m² [12]. CDW is a major component of solid waste in Saudi Arabia, leading to issues such as resource depletion, land degradation, and pollution from dust and toxic discharges [13]. Despite the degradation of natural environments, many global economies still follow the linear economic model, characterised by a “take-use-dispose” approach [14]. This model has proven inefficient and unsustainable in the long term [15], given its dependence on non-renewable resources, production of short-lived goods, and significant waste generation [16]. The linear economy is unable to sustainably meet the resource needs of a growing global population [17]. Rapid economic growth and urbanisation worldwide have exacerbated resource depletion and waste generation, underscoring the urgent need to transition to a circular economy to protect natural resources and ecosystems [18].

The circular economy promotes a “take-use-reuse” approach, aiming to close product life cycles by treating waste as a valuable resource, thereby reducing environmental impact [14]. The concept of CE dates back to the 1960s and has since gained traction among researchers and practitioners as an alternative to the linear economy. Various definitions of CE exist, but Kirchherr et al. [19] describe it as an economic system that redesigns the “end-of-life” phase of the linear model through reduction, reuse, and recycling of resources, aiming for sustainable development and long-term benefits. Environmental economists Pearce and Turner introduced this concept in 1990, highlighting the environment as a life-support system rather than merely a resource source, advocating for decoupling economic growth from resource use to enhance sustainability and competitiveness [20]. CE addresses environmental challenges and promotes economic growth, global integration, and long-term sustainability [21].

The transition to a circular economy (CE) has gained momentum worldwide, with various nations adopting unique approaches to sustainability and resource efficiency. While some countries have developed comprehensive strategies to integrate CE principles into their economies, others are making progress through indirect initiatives and sector-specific policies. China is a global leader in CE, with significant progress in adopting circular business models and implementing top-down, system-level strategies that serve as a valu-

able example for other developing nations pursuing sustainable economic models [22,23]. Europe has also shown a strong commitment to CE principles, with countries like Germany and the Netherlands recognised as pioneers in circular practices, demonstrating competitiveness and progress in sustainability [24,25]. Japan, known for its innovative approaches to sustainability and resource management, showcases the benefits of CE practices through industrial transformation in cities such as Kitakyushu, providing insights into achieving economic resilience through sustainable practices [21,26]. Saudi Arabia's Vision 2030 [27] aims to reduce reliance on oil by diversifying the economy with a focus on sustainability and sustainable growth. However, the country lacks a dedicated circular economy strategy, despite some indirect initiatives.

To assess Saudi Arabia's progress and potential in circular economy adoption, this study compares the country's CE practices with those of leading nations like China, Europe, and Japan, which have successfully implemented CE strategies. Although there is existing research on Saudi Arabia's circular economy, no direct comparisons have been made with global leaders. This study's findings provide valuable insights for advancing Saudi Arabia's circular economy efforts and fostering sustainability.

2. Methodology

A comparative analysis was conducted to evaluate the circular economy in Saudi Arabia, benchmarking it against practices in leading countries. Qualitative data were collected through a flexible design study, which is well-suited to achieving the research objectives. To establish a strong foundation for the methodology and to select the most appropriate approach, a broad range of academic papers was thoroughly reviewed. This process involved organising relevant studies, followed by a systematic analysis. A total of 22 papers were reviewed and categorised based on relevance, using a colour-coded system. From this review, two studies were identified as particularly relevant, Herrador & Van [18] and Herrador et al. [21]. These papers provided valuable insights that shaped the research design and implementation. The methodological approach of these two studies served as a foundation for this study.

The primary goal of this research is to compare the strategies and achievements of leading CE nations with Saudi Arabia, a developing country seeking to diversify its economy and reduce waste. This research also maps the pathway for developing nations like Saudi Arabia to transition to a circular economy. The sub-objectives are as follows:

- Identify the initiatives and opportunities available to Saudi Arabia.
- Benchmark leading countries by examining their established policies and strategies.
- Develop a framework to compare circular economy practices across various countries.
- Analyse these policies using thematic analysis and provide recommendations to support Saudi Arabia's successful adoption of CE practices.

A comprehensive search strategy was applied to gather relevant literature, utilising specific search operators and keywords, such as "Circular AND Economy" AND "waste AND management" AND "Policy" "Macro" "KSA" "Saudi Arabia" "recycle" AND "comparative OR comparison OR comparing" to maximise search results. The review process involved several steps. This research primarily relied on secondary data sources for data collection, selecting sources to ensure data quality. The main information sources included:

- Databases and Academic Journals: Major databases like Scopus, ResearchGate, and Google Scholar were accessed to retrieve a wide array of academic papers.
- Governmental and Industry Websites: Official websites of government organisations, such as Eurostat and Vision 2030.

This study employs a structured framework for comparing circular economy policies, incorporating several key components. Policies and strategies from the selected countries were gathered from credible sources such as government websites and academic journals. The data collected were categorised according to eight key elements, developed by the authors through a detailed analysis of content from Saudi Arabia and leading CE nations. These elements emerged from the analysis as follows:

- Policies and Strategies
- Economic and Financial Opportunities
- Resource Management
- Innovation and Technology
- Social Aspects
- Monitoring Framework
- Sustainability Outcomes
- Future Planning

For this study, the policies and strategies of the selected countries were thoroughly analysed. An in-depth review of the literature was conducted to examine the initiatives, policies, and strategies. The collected data were organised into a structured format within an Excel database. Data analysis involved thematic analysis to identify key themes, patterns, and practices, highlighting similarities and differences [28]. The data were coded based on predefined categories, resulting in various themes. These themes, developed by the author after conducting a thematic analysis of both Saudi Arabia and the leading CE countries, are as follows:

- Government Strategies, Policies, and Initiatives
- Economic Opportunities and Challenges
- Waste Management and Recycling
- Technological Integration and Innovation
- Social and Community Engagement Indicators
- Policy Outcomes
- Future Projects.

The framework used in this study for comparing circular economy policies involves several key components. Policies and strategies from the chosen countries will be gathered through reliable sources such as governmental websites and academic journals. The collected data will be categorised based on eight elements that the author developed through an analysis of the content from both Saudi Arabia and leading countries in the circular economy. The formation of these elements is a result of the analysis that has been done.

3. Comparison of Circular Economy Strategies

This section presents a comparative analysis of circular economy strategies and policies in Saudi Arabia, Europe, Japan, and China. Using the comparative framework outlined in the methodology, this analysis examines each framework element to reveal shared strategies and distinct approaches among these regions. The aim is to gain insights into the effectiveness of different CE strategies and policies. The findings will be summarised and categorised within the framework, followed by a discussion which will interpret the results and outlining the implications for policy and practice.

3.1. Saudi Arabia

In 2016, Saudi Arabia introduced Vision 2030 to address economic and environmental challenges by diversifying its economy and promoting sustainability. Key sustainabil-

ity goals within Vision 2030 include advancing renewable energy, enhancing waste-to-energy processes, improving recycling practices, and reducing greenhouse gas (GHG) emissions [27,29]. Vision 2030 also aims to generate ecological and economic benefits, such as creating jobs through sustainable practices. According to The Economist Intelligence Unit [8], the Saudi Investment Recycling Company (SIRC) intends to contribute over 10 billion USD to the GDP and create 23,000 new jobs by 2030. Additionally, the Saudi Green Initiative, launched in 2021, seeks to reduce GHG emissions by more than 278 million tonnes annually, increase renewable energy production to 50% of the national energy mix, cut carbon emissions by over 4%, and plant 10 billion trees by 2030 [30].

3.1.1. KSA Initiatives

A. Waste management

In 2017, the Saudi government allocated SAR 54 billion to improve drainage and waste management systems, alongside other municipal services. This investment supported the launch of various recycling and waste management initiatives, including the approval of new policies to establish a municipal solid waste (MSW) system [31]. By 2035, Saudi Arabia aims to recycle 42% of waste, compost 35%, incinerate 19% for energy production, and manage the remaining 4% through other methods [10]. The Saudi Public Investment Fund (PIF) established the SIRC to oversee waste management projects, targeting an 81% recycling rate by 2035 [8]. SIRC's mission is to collaborate with the private sector, support the circular economy, and attract both local and global investments to advance the Kingdom's sustainability efforts. SIRC oversees several key initiatives, namely [32,33]:

- Maximising resource efficiency that involves developing processes and facilities to handle various types of waste and convert them into reusable materials or energy.
- Infrastructure development where a focus on building advanced recycling and waste management plants for municipal solid waste, industrial waste, and construction and demolition waste
- Waste-to-energy projects to reduce landfill waste while generating renewable energy, aligning with Vision 2030's goals to increase the share of renewable energy in the country's energy mix.

The National Centre for Waste Management [34], established in 2019, was created to regulate the waste sector by overseeing activities across the entire waste management cycle. The centre is also responsible for issuing licenses and permits to establishments, investors, and stakeholders involved in waste management. Additionally, the National Centre for Waste Management introduced a sustainable initiative aimed at achieving the following objectives [34]:

- To secure commitments from institutions to implement waste reduction and recycling initiatives by applying circular models.
- To save the environment by following best practices to reduce waste and maximise its benefits.
- To ensure the adoption of a circular economy by developing a real plan to apply the 3Rs (Reduce, Reuse, Recycle).
- To spread awareness and engage the community in preserving the environment through waste reduction practices.
- To promote corporate responsibility by transferring the knowledge of waste management concepts and correcting common societal behaviours.

SIRC and the Riyadh Municipality have formed a partnership to reduce landfill waste in Riyadh, aiming to decrease municipal solid waste by 81% and construction and demolition waste by 47% by 2035 [35]. To support these efforts, SIRC acquired Global

Environmental Management Services (GEMS), a company specialising in industrial recycling, to enhance its recycling capabilities within Saudi Arabia and to export domestically developed technologies (The Economist Intelligence Unit, 2021). Additionally, the city of Riyadh introduced a food recycling initiative called “City without Containers”, which encourages residents to separate organic waste using a two-bin system [7].

B. Energy

Saudi Arabia’s Vision 2030 places a strong emphasis on environmental protection and the adoption of renewable energy sources [27]. The Circular Carbon Economy (CCE) strategy, adopted by Saudi Aramco, seeks to minimise environmental pollution through the 4Rs framework: Reuse, Recycle, Reduce, and Remove carbon emissions from the atmosphere. Aramco actively monitors energy intensity in its oil and gas operations and engages in carbon capture efforts, including planting 13.3 million mangrove trees as of 2024, with plans for further expansion. In addition, the Saudi Arabian Basic Industries Corporation (SABIC) supports the CCE by converting CO₂ into fertilizers and methanol and collaborates with SIRC to produce pyrolysis oil from mixed plastic waste [36]. SIRC also intends to invest in waste-to-energy plants to help Saudi Arabia reach a 3 GW waste-to-energy capacity by 2030 [37]. Vision 2030 further aims to decarbonise electricity generation through renewable energy sources [36]. Since 2019, Saudi Arabia has increased its use of renewable energy for power production, revising its original target of 9.5 GW by 2023 to 58.7 GW by 2030, which will constitute 50% of the country’s power generation [38].

3.1.2. Opportunities

In Saudi Arabia, circular economy (CE) initiatives are currently integrated into various governmental frameworks and sector-specific policies. The opportunities for the country to adopt a CE strategy include the following:

- Conducting thorough planning before implementing a CE strategy could create favourable conditions and attract investment for key CE activities [36].
- Policies that provide clear guidelines and support can encourage stakeholders to adopt CE practices, facilitating a smoother transition toward circularity [3].
- Engaging community leaders—such as public figures and experts in promoting sustainable living and resource efficiency could foster greater acceptance of the CE concept [36].
- Adopting a circular economy could help Saudi Arabia diversify its economy away from dependence on finite oil resources and reduce excessive waste levels [8].

3.2. Europe

3.2.1. Strategies and Policies

In 2014, the European Commission (EC) adopted the circular economy as the European Union’s (EU) new economic model [39]. The following year, in 2015, the EC launched its first action plan, ‘Closing the Loop—EU Action Plan for the Circular Economy’ aimed at making the EU economy more sustainable [20]. This plan includes 54 actions designed to promote circular economy principles across various sectors [40]. These actions focused on waste reduction, sustainable product design, and improved recycling systems, with significant progress in these areas since implementation. In 2019, the EC introduced the Green Deal, which incorporated an updated strategy to further the shift to a sustainable circular economy [20]. This strategy aims to make the EU a more resource-efficient and competitive economy, positioning Europe as the first climate-neutral region by 2050 [41].

Additionally, by 2030, EU nations aim to reduce emissions by 55% compared to 1990 levels. The strategy promises various benefits, including the creation of green jobs, new opportunities, and enhanced quality of life for European citizens [41]. Achieving climate neutrality by 2050 requires the EU to decouple economic growth from resource consumption

and shift towards circular systems in production and consumption [42]. In 2020, the EC introduced a new CE Action Plan to drive growth while adhering to global environmental constraints, focusing on reducing consumption footprints and doubling circular material usage rates [39]. The plan includes over 30 initiatives, targeting the creation of sustainable products, promoting circularity in production processes, and empowering consumers and public buyers. To monitor progress in the circular economy, the EC implemented a framework with ten indicators covering aspects such as secondary raw materials, waste management, production, consumption, and competitiveness [43]. The circular economy has become a primary focus for the EU, with numerous policies and regulations introduced to foster this transition, stimulate the economy, enhance competitiveness, and ensure sustainable growth [14]. Figure 1 shows a timeline of major strategies for the European circular economy.

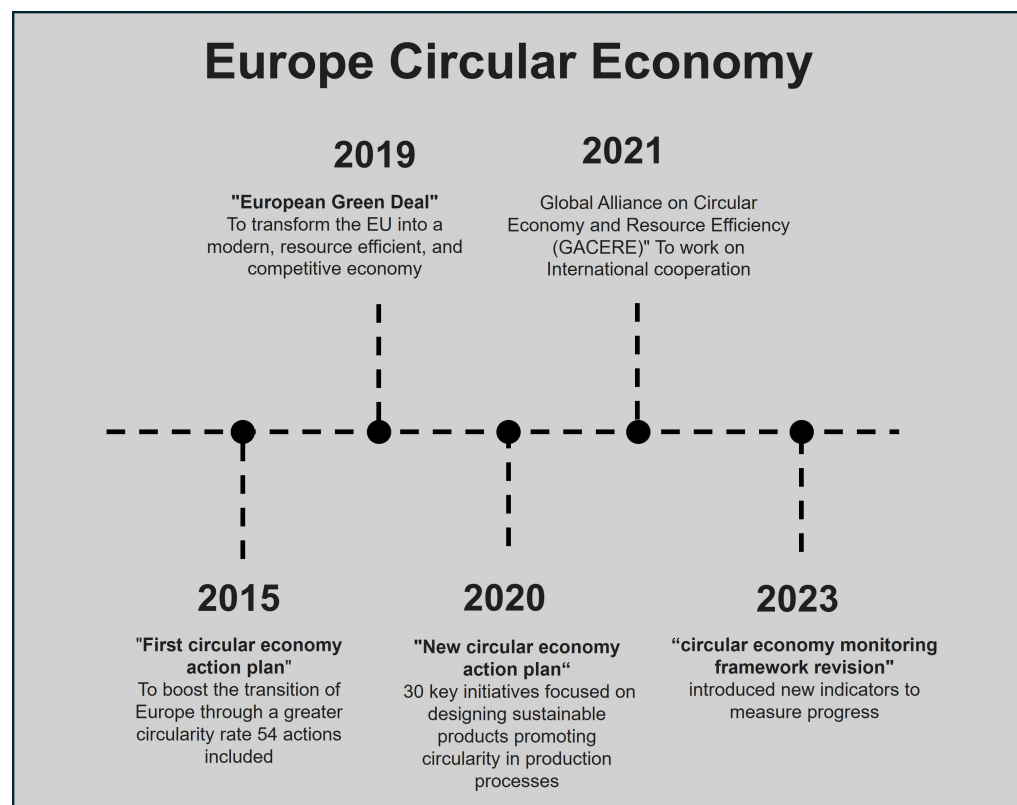


Figure 1. Europe CE Timeline.

3.2.2. Outcomes and Future Directions

Several countries, including the Netherlands, Germany, Italy, and Belgium, have introduced national policies aimed at advancing the circular economy. Eurostat's monitoring framework indicates that both the circular usage rate and resource productivity in Europe have improved since the first European action plan was implemented in 2015, extending through 2023 [44]. The Netherlands, in particular, has demonstrated a strong commitment to circularity, establishing itself as a leader in the recycling industry, as illustrated in Figure 2. Circularity rates and resource productivity have generally improved across most European nations, as shown in Figures 2 and 3. Countries with circular economy strategies in place have observed an increase in municipal waste recycling rates between 2014 and 2019. Germany leads with a recycling rate nearing 70%, followed by the Netherlands, Belgium, Austria, and Slovenia [39].

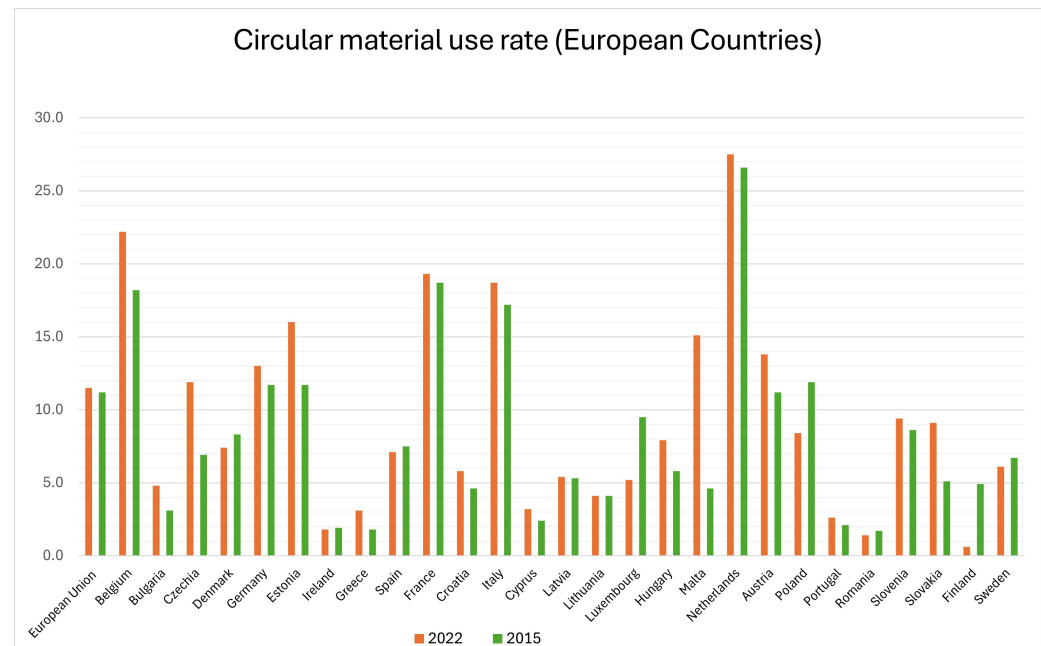


Figure 2. Circular material use rate of Europe [44].

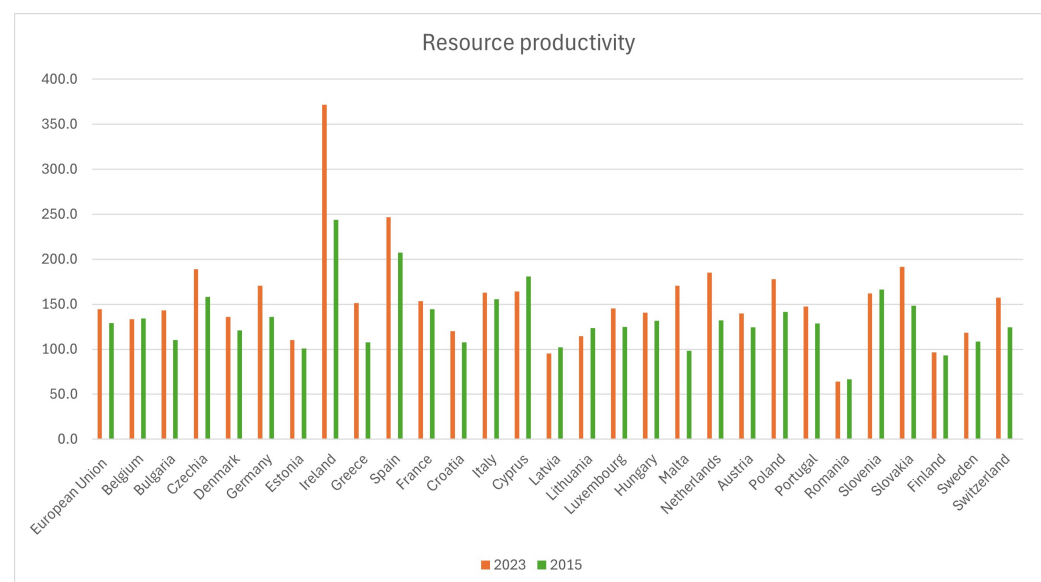


Figure 3. Resource Productivity of Europe [44].

3.3. China

3.3.1. Strategies and Policies

China's rapid economic growth has positioned it as a major global economic power, but this development has also led to significant resource depletion and environmental degradation, compounded by continued population growth [45]. In an effort to address these challenges, China is working towards achieving the 17 sustainable development goals by promoting the Circular Economy [26]. Prior to 2002, the Chinese government took steps to promote the concept of CE to enhance resource productivity and implement environmental regulations [46]. In 2002, China formally integrated the idea of Circular Economy into its national policies [47]. As part of this, China has developed a comprehensive set of CE indicators at various levels—macro, meso, and micro [48]. In 2005, China introduced the “Opinions on Accelerating the Development of Circular Economy” which outlined the foundational ideology, principles, and policy measures to advance CE [47]. This policy included specific financial, tax, and investment strategies to support CE implementation [49].

Following this, in 2009, China passed the Circular Economy Promotion Law, providing a key framework for advancing CE [50]. The legislation emphasised the importance of CE for the country's economic and social development, incorporating the “reduce, reuse, recycle” principles and establishing various institutional measures [46].

In 2012, President Hu Jintao declared CE as a central strategy for building an ecological civilisation [49]. The National Development and Reform Commission (NDRC) and the Ministry of Environmental Protection (MEP) are the two primary bodies responsible for regulating CE in China [51]. In the 13th Five-Year Plan, the NDRC introduced the Circular Development Leading Action Plan, a significant national policy aimed at addressing environmental and social challenges while leveraging digital technologies. This policy emphasises applying CE principles early in the design phase of products and business models [48]. Its goal is to create a new resource strategy and circular development system focused on reducing emissions and consumption, increasing resource efficiency, and promoting a green lifestyle [49]. In 2020, China introduced the “dual circulation” policy, a national economic reorientation that prioritises domestic circulation. Subsequently, the 14th Five-Year Action Plan on Circular Economy was approved, outlining objectives for national resource security, conservation, and recycling”. This plan also highlights the critical role of CE in addressing climate change, with an ambitious target of achieving carbon neutrality by 2060 [47]. The 14th Five-Year Plan includes a range of sustainability objectives, all aimed at advancing CE goals. These targets include:

- Achieving 20% more resource productivity than in 2020.
- Reducing the amount of energy and water used per GDP unit by 13.5% and 16%, respectively, in comparison to 2020 levels.
- To process 320 million tonnes of scrap steel and using 60 million tonnes of wastepaper.
- To produce 20 million tons of recycled non-ferrous metals [48]. Figure 4 depicts the journey of key strategies for the Chinese circular economy.

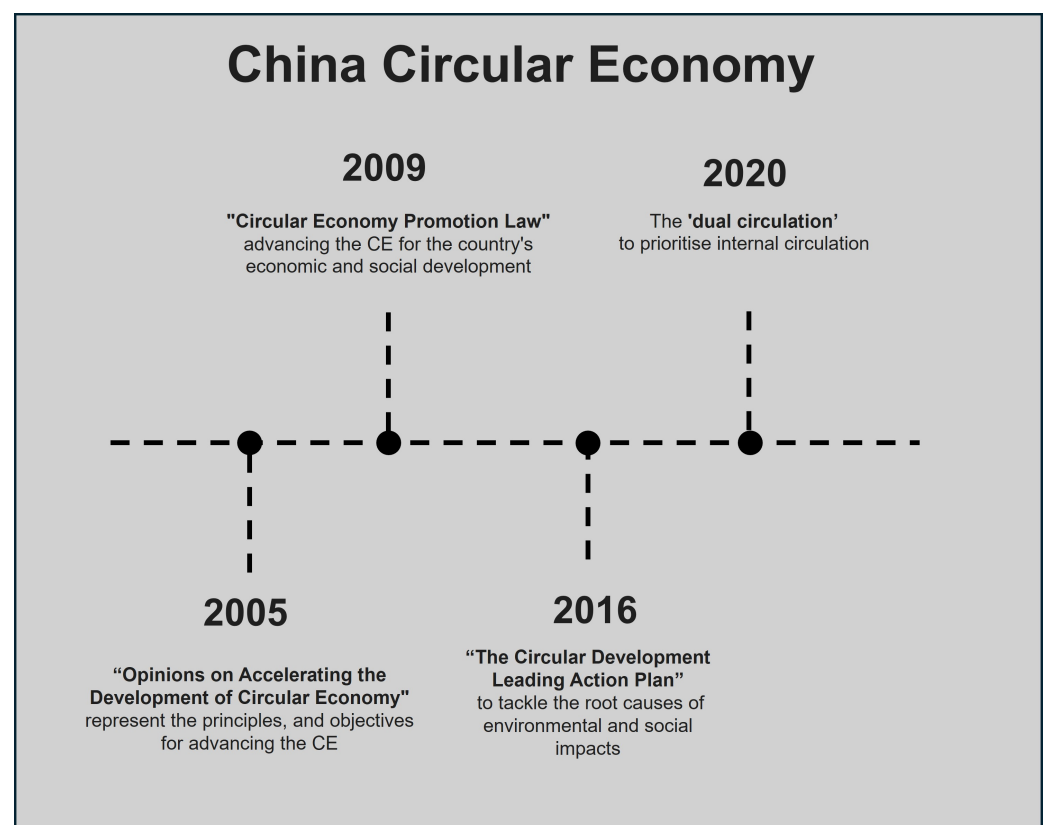


Figure 4. China's Circular Economy timeline.

3.3.2. Outcomes and Future Directions

For almost two decades, China has been implementing policies to promote a circular economy, making substantial progress through regulatory actions and administrative directives at the provincial, city, industrial, and factory levels [48]. Thanks to China's comprehensive circular economy policies and strategies, there has been a notable increase in resource productivity and circularity [16]. The outcomes of these efforts are presented in Table 1.

Table 1. Outcomes of China in advancing CE.

Outcome	Achievement	Source
Resource productivity	26% increase from 2015 to 2020	[47]
Circularity rate	Circularity rose from 2.7% to 5.8% from 1995 to 2015	[16]
Recycling of end-of-life waste	Increased from 7.2% to 17%	[16]
Decoupling of GDP from resource use	Relative decoupling of GDP achieved	[48]
Resource intensity	Drop from 4.3 kg of materials per unit GDP in 1990 to 2.5 kg in 2011	[46]

3.4. Japan

3.4.1. Strategies and Policies

Japan, an island nation with a large population, has been driven toward circularity due to the scarcity of landfill space, constrained by the country's rocky terrain, and the lack of domestic sources of metals and minerals, despite its considerable industrial output [52]. In 1991, Japan became the first country to introduce circular economy legislation by updating the Waste Management Act and enacting the Effective Resource Utilisation Promotion Act [21,52]. Subsequently, the "1999 Circular Economy Vision" aimed to transition from mass production to a circular economy that incorporates both economic and environmental considerations. Japan's waste and recycling regulations expanded from the 1R (recycle) to the 3Rs (reduce, reuse, recycle) [53]. This Vision was structured into four key chapters:

- The Way Forward to a Circular Economy System,
- Reconstruction of Waste Management and Recycling Measures,
- Future Challenges and Policy Responses for Establishing CE,
- Current Status and Issues in Individual Areas [53].

In 2001, Japan launched the Sound Material-Cycle Society (SMCS) initiative [54]. Led by the Ministry of Environment (MoE), the SMCS strategy addresses both domestic and global socio-economic challenges. It prioritises international collaboration on circular economy issues while fostering sustainable long-term economic growth to combat stagnation [55].

The strategy promotes the transition from a linear model to a circular one through the effective implementation of the 3Rs [55]. The updated SMCS framework includes 151 indicators to track progress until 2025 [21].

In 2019, Japan introduced a strategy to circulate plastic resources aiming at reducing plastic, packaging, and container use. The strategy set the following goals:

- By 2025, recycle and reuse designs for plastic packaging and containers.
- By 2030, reduce single-use plastic waste generation by 25%, recycle and reuse 60% of plastic packaging, and double the amount of recycled plastic.
- By 2035, achieve full reuse of all plastics [21].

The Ministry of Economy, Trade, and Industry (METI) released the Circular Economy Vision 2020, which underscores Japan's shift towards a circular economy [55]. This Vision

seeks to promote the transition to a circular economy at all levels of society and outlines the expected actions of all involved parties [21]. It also supports the advancement of digital technologies in line with Japan's Society 5.0 vision, which aligns with the Sustainable Development Goals. Additionally, the Vision highlights the importance of investments in governance, society, and the environment as crucial drivers of this transformation [21]. Figure 5 illustrates the timeline of key strategies in Japan.

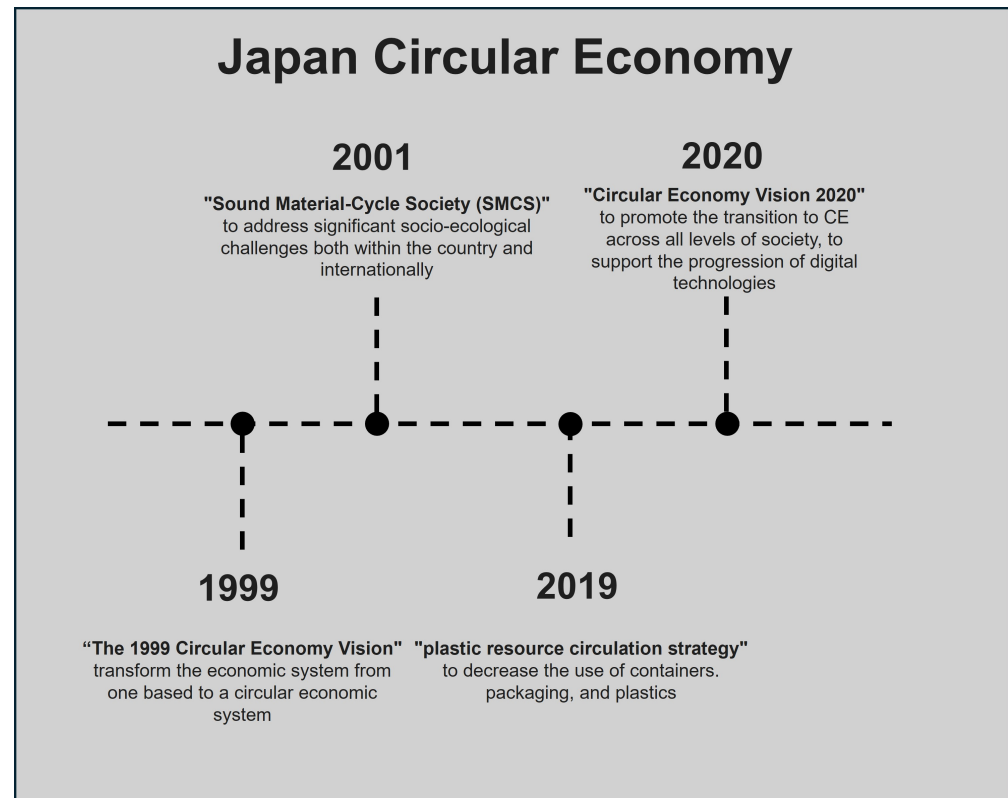


Figure 5. Japan Circular Economy.

3.4.2. Outcomes and Future Directions

Japan is a leader in advancing the circular economy, having established one of the most comprehensive legislative and recycling frameworks globally. Table 2 indicates some of the outcomes of advancing CE in Japan.

Table 2. Outcomes of Japan in advancing CE.

Outcome	Achievement	Source
Recycling rate of metals	98% recycled	[54]
Recycling rate of materials	Between 74% and 89% recycled	[54]
Cyclical use rate	Rose from 10% to 15,4% from 2000 to 2016	[53]
Waste generated	significant reduction	[53]
CE technology patents	Japan holds the highest share, accounting for 28%	[54]
Decouple the use of non-renewable resources	Enabled by high technology and expertise	[52]

Technological advancements in Japan, China, and the EU are shaping the CE through digital transformation, advanced recycling methods, and sustainable manufacturing. Japan leads in end-of-life vehicle recycling, leveraging strict regulations and sophisticated technologies to maximise material recovery [56,57]. Additive manufacturing is increasingly

utilised to recycle waste plastics, while IoT, Big Data, and Blockchain enhance supply chain traceability and efficiency [58]. Also, the role of technology in advancing the circular economy in China is multifaceted. Technological innovations such as big data analytics, blockchain, and IoT are pivotal in enhancing resource efficiency, waste reduction, and transparency in supply chains. Key technologies driving CE, such as Big Data Analytics, enable better resource management and consumer behaviour analysis, leading to optimised supply chains [59]. Also, blockchain technology enhances transparency and traceability in product lifecycles, as seen in the electronics and food supply chains [60]. Moreover, the Internet of Things supports real-time resource monitoring, improving waste management efficiency [59]. Conversely, the EU focuses on digital and energy technologies to support CE initiatives, aligning them with climate neutrality goals and data-driven business models [61,62]. R&D investments under the European Green Deal drive innovation, though challenges remain in scaling pilot projects and balancing CE progress among member states [62].

4. Discussion

The comparison between Saudi Arabia and leading countries reveals that, while Saudi Arabia has introduced Vision 2030 and various initiatives, it still lacks a comprehensive strategy and policies to achieve the level of progress seen in these countries, which have succeeded through sustained, long-term efforts. This section will examine the framework elements outlined in Table 3. Japan was the first country to adopt the circular economy in 1991 [52], followed by China and then Europe. Despite Europe's relatively late start in 2015, it has become a leading region in embracing the circular economy, achieving substantial success due to its strong commitment to circular economy strategies. In the first EU action plan, Europe set 54 actions, all of which have been completed [40].

Table 3. Comparison analysis framework.

Framework Element	Themes	Saudi Arabia	Europe	China	Japan
Policies and Strategies	Government Strategies, Policies and Initiatives	<ul style="list-style-type: none"> • Vision 2030. • Circular Carbon Economy. • Saudi Green Initiative. • SIRC initiatives. • Sustainable initiative by NCWM. 	<ul style="list-style-type: none"> • EU Circular Economy Action Plan includes 54 actions (2015). • European Green Deal (2019). • New Circular Economy Action plan includes 30 key initiatives (2020). 	<ul style="list-style-type: none"> • Opinions on accelerating the development of circular economy (2005). • Circular Economy Promotion Law (2009). • The Circular Development Leading Action Plan (2016). • The ‘dual circulation’ (2020). 	<ul style="list-style-type: none"> • Effective Resource Utilisation Promotion Act (1991). • The 1999 Circular Economy Vision. • Sound Material-Cycle Society (SMCS) (2001). • Circular Economy Vision (2020).
Economic Financial Opportunities	Economic Opportunities and Challenges	<ul style="list-style-type: none"> • Investment in Saudi green initiative. • Investment to improve municipal waste. • SIRC’s plan to attract investment locally and globally. 	<ul style="list-style-type: none"> • Decoupling economic growth from resource use. • Drive economic growth (New CE action plan). 	<ul style="list-style-type: none"> • Financial, tax, and investment strategies to support the implementation of CE, according to “Opinions on accelerating the development of circular economy” strategy. • Decoupling of GDP from resource use. 	Not Implemented.

Table 3. Cont.

Framework Element	Themes	Saudi Arabia	Europe	China	Japan
Resource Management	Waste Management and Recycling	<ul style="list-style-type: none"> Plans to improve waste-to-energy conversion, enhancing recycling efforts according to Vision 2030. Waste Management and Recycling 	<ul style="list-style-type: none"> High recycling in municipal waste from 2014 to 2019. Greater circularity rate such as recycling according to the EU's first action plan. Transform the EU into a modern, resource-efficient, and competitive economy (Green Deal). Doubling the rate of circular material use. 	<ul style="list-style-type: none"> New resource strategy for resource efficiency and promote a green lifestyle according to 13th action plan. Increasing resource productivity by 20 per cent relative to 2020 levels according to 14th action plan 	<ul style="list-style-type: none"> Effective Resource Utilisation Promotion Act. Circular use of resources development, and reconstruction of Waste Management according to 1999 circular economy vision
Innovation and Technology	Technological Integration and Innovation	Plans to locally develop technology to expand the capacity of recycling within Saudi Arabia	Not Implemented	<ul style="list-style-type: none"> Tackle the root causes of impacts while focusing on new digital technologies (The Circular Development Leading Action Plan). Circular economy in China includes technological innovation. 	The new Circular Economy Vision supports the progression of digital technologies.

Table 3. Cont.

Framework Element	Themes	Saudi Arabia	Europe	China	Japan
Social Aspects	Social Community Engagement	<ul style="list-style-type: none"> Generating jobs by adopting a circular economy in the future “City without Containers” encourages households to separate organic waste Spread awareness and engage the community in preserving the environment and “NCWM” 	<ul style="list-style-type: none"> Creation of new green jobs and opportunities “Europe action plan (2015)” Improvements in the quality of life for European citizens (European Commission, 2019) 	<ul style="list-style-type: none"> Circular Economy is a key strategy for the country’s economic and social development. In 2012, President Hu declared that Circular Development is a national strategy for building an ecological civilisation. 	<ul style="list-style-type: none"> The SMCS strategy to address significant socio-ecological challenges. Circular Economy Vision 2020 to promote the transition to a circular economy across all levels of society. Japan developed a circular economy society by effectively integrating its population, economy, and social system.
Monitoring Framework	Indicators	No monitoring framework and indicators were implemented.	Created a monitoring framework to measure progress towards a circular economy, it consists of 10 indicators.	China has developed a set of comprehensive Circular Economy indicators at various macro, meso, and micro levels.	SMCS framework includes 151 indicators for monitoring progress until 2025.

Table 3. Cont.

Framework Element	Themes	Saudi Arabia	Europe	China	Japan
Sustainability Outcomes	Outcomes of the policies	No outcomes since Saudi is newly emerging in CE.	<ul style="list-style-type: none">Netherlands, Germany, Italy, and Belgium have implemented dedicated national policies to promote the circular economy.Increase in municipal waste recycling from 2014 to 2019.Germany nearly achieved 70% recycling. Germany’s status as a CE fore-runner.	<ul style="list-style-type: none">Resource productivity saw a 26% increase from 2015 to 2020.Circularity rose from 2.7% to 5.8% between 1995 to 2015, recycling of end-of-life waste improved from 7.2% to 17% throughout the same period.Drop in resource intensity from 4.3 kg of materials per unit GDP in 1990 to 2.5 kg in 2011.Improvements in resource productivity and circularity.	<ul style="list-style-type: none">Recycling rate of 98% for metals and between 74% and 89%for materials from home appliances in 2014.Japan is the highest portion of circular economy technology patents worldwide, accounting for 28%.Significant reduction in the amount of waste generated.Cyclical use rate increased from 10% in 2000 to 15.4% in 2016.

Table 3. Cont.

Framework Element	Themes	Saudi Arabia	Europe	China	Japan
Future Planning	Future projects	<ul style="list-style-type: none"> SIRC aims to contribute over US\$10 billion to the GDP and create 23,000 new jobs by 2030. By 2035, Saudi Arabia plans to adopt a new waste management strategy. SIRC aims to achieve a recycling rate of 81% by 2035. SIRC plans to invest in waste-to-energy plants to help Saudi Arabia achieve a 3 GW waste-to-energy capacity by 2030 	<ul style="list-style-type: none"> Make Europe the first climate-neutral region by 2050. European countries are committed to reducing emissions by 55% by 2030 compared to 1990 levels. 	<ul style="list-style-type: none"> Tackling climate change and achieving carbon neutrality by 2060. Increasing resource productivity by 20 per cent relative to 2020 levels. Decreasing energy and water consumption per unit of GDP by 13.5 per cent and 16 per cent, respectively, also compared to 2020 levels. Utilising 60 million tons of waste paper and processing 320 million tons of scrap steel. Producing 20 million tons of recycled non-ferrous metals. 	<ul style="list-style-type: none"> By 2025, ensure that plastic packaging and containers are designed to be recyclable and reusable. By 2030, achieve a 25% reduction in the generation of single-use plastic waste. Recycle and reuse 60% of plastic packaging, double the utilisation of recycled plastic. By 2035, achieve the reuse of all plastics.

4.1. SWOT Analysis

To give a summarised understanding of the comparisons introduced earlier, SWOT analysis has been conducted and demonstrated in Figure 6.

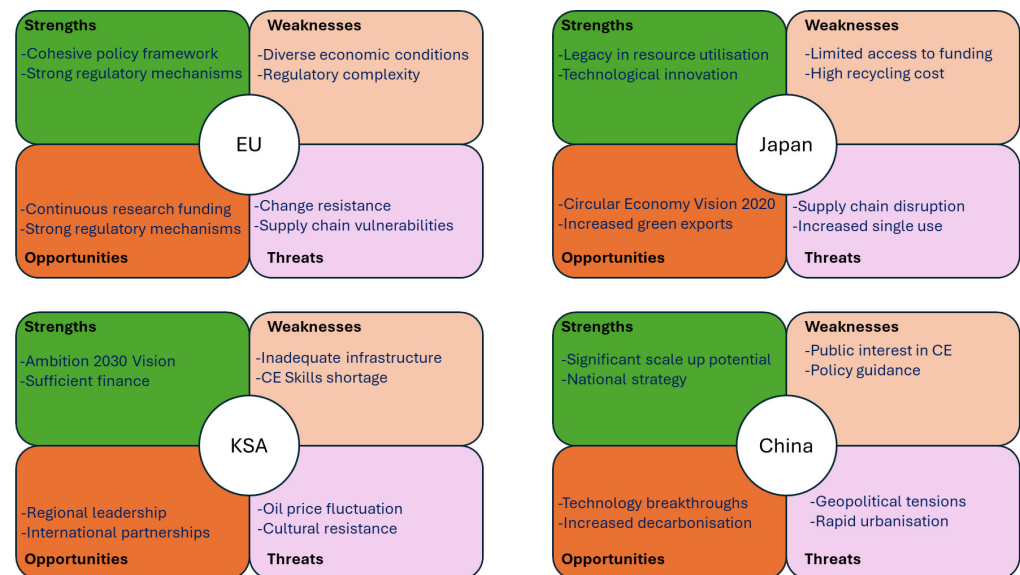


Figure 6. SWOT analysis.

The EU has a strong policy framework which allows for transferring CE from a desired economic model to a legal requirement. Further, the EU facilitates the transition through research and development funding (e.g., the twin transition), allowing manufacturers to test new technologies. On the other hand, the aforementioned legislation may hinder the growth of Small and Medium Enterprises (SMEs) as they face more requirements to comply with. Another complication is that the EU's supply chain may face disruption when the providers can not comply with legislation.

With its huge economy, China's ability to scale up CE initiatives is significant with the availability of test beds from various industries. These initiatives are manifestations of the national strategy exemplified in the "Dual Circulation" and "Circular Economy Promotion plan mentioned earlier. Meanwhile, the advancement in technology holds remarkable potential for China to advance CE practices. Some outputs are explained earlier, such as increased circularity rate and resource productivity. A noticeable weakness for China is public participation, as noted by [45], who call for measures to encourage public participation in CE development. Another weakness is the policy guidance mechanism, where not all provinces have regional CE policies.

The scarcity of resources in Japan motivated a mindset of resource preservation and wise consumption, which created a legacy of acceptance of CE further supported by enabling technologies. In addition, the opportunity for Japan to become an important source for green exports [21] is remarkable. However, access to public funding is limited for projects that are pre-established within public administration [21]. Lastly, Japan's vulnerability to natural disasters and resource scarcity underscores the realistic threat of supply chain disruptions.

Based on the facts presented above, the weaknesses and threats of Saudi Arabia's adoption of CE become more evident. Other economies considered as a benchmark established strategic vision supported by legislative frameworks and technological infrastructure, whereas these elements are still underdeveloped in Saudi Arabia. Moreover, there are threats that exist and restrict CE advancement in terms of oil price fluctuations and culture

aspects. Nevertheless, Saudi's regional leadership and financial resources will empower the efforts toward CE adoption.

4.2. Economic and Financial Opportunities

Decoupling economic growth from resource consumption is one of the main goals of the circular economy, a target that has been realised by leading countries. However, since Saudi Arabia is relatively new to adopting the circular economy, the country is currently focusing on investments to foster decoupling economic growth and enhancing its GDP in the future, rather than establishing incentives or setting specific targets for decoupling economic growth as seen in China and Europe. Japan has implemented a comprehensive strategy focused solely on the proper management and utilisation of resources [21]. Likewise, both Europe and China have made significant strides in recycling and have considerably improved resource productivity [16,39]. Saudi Arabia, in its Vision 2030, has outlined plans to develop recycling initiatives, with the Saudi Investment Recycling Company setting strategies to enhance resource efficiency in the region. However, these plans have not yet been fully realised. Japan places great emphasis on community involvement and highlights this aspect in its strategies. For example, the 2005 Sound Material-Cycle Society (SMCS) strategy identified solutions for social and economic challenges within the context of the circular economy as one of its most significant objectives [55]. While China's model is more centralised, its president has stated that developing a circular economy is a national strategy and a key approach to building an ecological civilisation [49]. Similarly, in Europe, the shift to a circular economy has created job opportunities [41].

These insights could be valuable for Saudi Arabia as it adopts the circular economy, potentially fostering job creation and raising community awareness by integrating these elements into its circular economy strategy, as seen in leading countries. Leading countries have developed performance metrics, often referred to as monitoring frameworks, to track the progress of circular economy implementation. For example, in China, the framework has highlighted significant regional disparities, with the eastern and central areas of the country showing much better circular economy rates compared to the west [46]. This monitoring framework has been crucial in identifying these differences. Therefore, once Saudi Arabia establishes its circular economy strategy, it would be advisable to set specific indicators to measure progress and evaluate the implementation of the circular economy.

The EU generously funds the transition to CE through programs such as Horizon 2020 (€95.5) and the LIFE program (€5.4). In addition, the finance and advice for circular economy projects are provided by the European Investment Bank (EIB) through the InvestEU Advisory Hub [63]. According to the International Energy Agency (IEA) [64], China's 14th Five Year Plan on circular economy (covering 2021 to 2025) aims to increase the output value of the resource recycling industry to RMB 5 trillion. China has invested more than 10 billion yuan in a special fund for key CE projects [48]. This fund focuses on areas like urban mineral resources (e-waste, waste plastics, construction waste), kitchen waste utilisation, industrial park transformation, recycling, remanufacturing, and clean production technology. This state investment of over 10 billion yuan is estimated to have driven social investment of more than 100 billion yuan. Bleischwitz et al. [48] also mention the establishment of a national carbon market with an emissions trading system, which is a significant financial mechanism that could drive decarbonisation efforts that align with CE principles. For Japan, the Green Growth strategy towards 2050 anticipates that investments of over 150 billion yen will be encouraged to advance low-carbon facilities through the use of operational leases [21]. Regarding the financial mechanisms for renewable energy, Japan has employed the Feed-in Tariff and the Renewable Portfolio Standard.

4.3. Outcomes and Achievements

The outcomes underscore the successes and achievements of leading countries in adopting the circular economy. As noted in the literature, for example, China saw a 26% increase in resource productivity from 2015 to 2020. In Europe, municipal waste recycling rose from 2014 to 2019 [14], with Germany achieving nearly 70% recycling. Japan achieved a 98% metal recycling rate in 2014 and leads globally in circular economy technology patents, holding a 28% share [52]. Additionally, Japan's circular use rate increased from 10% in 2000 to 15.4% in 2016. These accomplishments can serve as motivation for Saudi Arabia and other nations aspiring to adopt circular economy practices. It is also important to note that societal and research interest in the circular economy in Saudi Arabia, when compared to advanced countries, is a critical factor. As shown in Figure 7, data from Scopus indicates that the term "Circular Economy" has garnered more attention in China and Europe than in Saudi Arabia and Japan over the past five years.

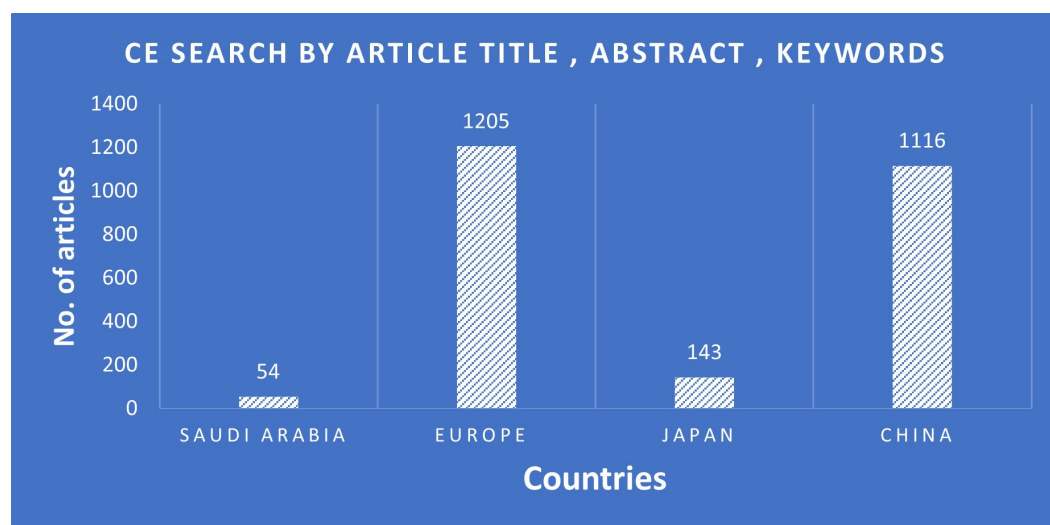


Figure 7. CE No. of research by country as reported in Scopus.

As noted in the literature [42,47,65], achieving net-zero carbon emissions is a goal embraced by all leading countries. Europe, in particular, has set an ambitious target to be the first region to reach net-zero carbon emissions by 2050 [42]. All leading countries have committed to advancing the circular economy, with a focus on reducing waste and increasing recycling rates. This shows that they not only implement strategies but also continuously set new, future-oriented targets. In contrast, Saudi Arabia has established goals such as reaching an 81% recycling rate and investing in converting waste into energy. However, these objectives are outlined through individual initiatives rather than being part of a clear, comprehensive strategy with accompanying policies, as seen in the leading countries. This suggests that Saudi Arabia should focus on developing a detailed, holistic strategy and follow the example set by these leading nations in this area.

4.4. Recommendations for Saudi Arabia

Based on the policies that the leading countries have implemented, analysed and discussed earlier, below are recommendations that support Saudi Arabia in adopting Circular Economy:

- Establish a centralised circular economy strategy that aligns efforts across all relevant entities and ensures stakeholder coordination to enhance efficiency and impact.
- Enhance the role of regulatory and legislative bodies in overseeing circular economy initiatives by providing strong institutional backing for effective implementation.

- Set specific, quantifiable goals within the circular economy strategy, such as the practice implemented by the leading countries.
- Offer incentives and support mechanisms to encourage private sector participation in adopting CE. Establish a digital transformation framework that institutionalises digital technologies (e.g., IoT and Big Data) to facilitate the execution of the circular economy strategy.

5. Conclusions

This research employs a comparative analysis approach to assess the current state of Saudi Arabia's circular economy and guide the country in adopting best practices from global leaders in this field. The first objective of the study was to evaluate the position of CE in Saudi Arabia by examining the existing policies and regulations that support circular practices. This was effectively addressed by identifying the initiatives outlined in the study which highlight Saudi Arabia's support for circular practices. The second objective was to examine the environmental, economic, and social challenges and opportunities confronting Saudi Arabia. This was achieved by discussing key environmental challenges within the Kingdom, particularly waste management. The third objective involved benchmarking leading countries by examining their established policies, strategies, and indicators. This was accomplished through a comprehensive analysis of the CE strategies and policies in each country. The final objective was to develop a framework for comparing circular economy practices across countries. This was accomplished by designing a comparative model for CE strategies and policies, enabling a discussion of policy similarities and differences. This framework not only clarified best global practices for Saudi Arabia to adopt but also offered valuable insights for other developing nations aiming to transition toward a circular economy.

This comparative analysis is limited by several factors, including the availability of data across the regions studied. Obtaining data was particularly challenging for countries where relevant information was not available in English, making data collection more difficult. Moreover, data collection within Saudi Arabia posed its own challenges, as the Kingdom does not publicly share data related to its contributions to the circular economy, which restricted the scope of the research. While the general concepts of strategies and policies may be similar, the internal agendas and actions of each country differ, which posed limitations on direct comparisons. Furthermore, the study did not include countries with economic structures similar to Saudi Arabia's, which may reduce the robustness of the conclusions drawn. Nonetheless, the core focus remained on comparing Saudi Arabia's circular economy practices with those of global leaders. Additionally, as Saudi Arabia is only beginning to embrace the concept of CE, comparing it with countries that have been implementing CE practices for over twenty years may limit the effectiveness of the comparison.

Future work could involve collaboration with experts from Saudi Arabia and leading countries to facilitate the acquisition of more accurate data. This comparison could be expanded to include a deeper exploration of the economic, social, and environmental dimensions. Incorporating quantitative data and working with relevant authorities to obtain precise figures would strengthen the analysis. Additionally, conducting a more focused comparison with countries that have industries and economies similar to Saudi Arabia's would add greater depth to the study. Future updates to this dissertation could explore new CE practices and progress made by Saudi Arabia and other leading nations. Furthermore, additional research could examine how policies are adapted and implemented at regional or local levels within each country, with a particular emphasis on the role of society, organisations, and local governments in influencing the outcomes of CE strategies.

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Abbreviations

The following abbreviations are used in this manuscript:

CDW	construction and demolition waste
CE	Circular Economy
EC	European Commission
EIB	European Investment Bank
GDP	Gross Domestic Product
GHG	Greenhouse Gas
IEA	International Energy Agency
MoE	Ministry of Environment
MSW	municipal solid waste
NDRC	National Development and Reform Commission
NCWM	National Centre for Waste Management
OECD	Economic Co-operation and Development
SIRC	Saudi Investment Recycling Company
SMCS	Sound Material-Cycle Society
SMEs	Small and Medium Enterprises

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