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A. K. Alhowaish * and Fatimah S Alkubur

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Article

Toward Unlocking the Potential of the Circular Economy at Municipal Levels: A Study of Expert Perceptions in the Dammam Metropolitan Area

A. K. Alhowaish [1,*] and Fatimah S. Alkubur [2]

[1] Department of Urban and Regional Planning, College of Architecture and Planning, Imam Abdulrahman Bin Faisal University, Dammam 31451, Saudi Arabia

[2] Department of Urban and Regional Planning, Imam Abdulrahman Bin Faisal University, Dammam 31441, Saudi Arabia

* Correspondence: ahowaish@iau.edu.sa

Abstract: The circular economy (CE) has emerged as a pivotal strategy for cities to reconcile economic growth with environmental sustainability. However, its implementation in resource-dependent Gulf Cooperation Council (GCC) contexts remains underexplored. This study investigates expert perceptions of CE readiness, barriers, and opportunities in the Dammam Metropolitan Area (DMA), Saudi Arabia, a critical industrial hub for Saudi Vision 2030. Through a cross-sectional survey of 230 policymakers, industry leaders, and academics, analyzed via descriptive and inferential statistics (SPSS) and qualitative coding (NVivo), this study identifies renewable energy (mean = 4.10) and municipal waste management (mean = 3.78) as top sectoral priorities. However, systemic challenges, including fragmented governance, limited public awareness (mean = 3.65), and funding gaps (mean = 3.52), underscore the gap between Vision 2030's ambitious targets and localized capacity. Statistical analyses reveal strong associations between institutional fragmentation and financial inefficiencies (X^2 = 23.45, p = 0.010), while mid-career workforce dominance (54.8%) and underrepresentation of policymakers (6.5%) highlight governance gaps. This study advocates for hybrid strategies: stricter waste regulations (40.0% stakeholder priority), CE training programs, and public–private partnerships (PPPs) to scale waste-to-energy infrastructure and industrial symbiosis. Despite pragmatic optimism (48.7% foresee 21–40% recycling by 2030), limitations such as reliance on expert perspectives and exclusion of citizen voices necessitate future interdisciplinary and longitudinal research. By aligning regulatory rigor with inclusive governance, the DMA can model a Gulf-centric CE transition, advancing regional sustainability while contributing actionable insights for resource-dependent economies globally.

Keywords: circular economy; municipal sustainability; Saudi Vision 2030; Gulf Cooperation Council (GCC); Dammam Metropolitan Area; stakeholder perceptions; waste management; institutional barriers

1. Introduction

The circular economy (CE) has emerged as a transformative paradigm to decouple economic growth from resource depletion and environmental degradation, offering systemic solutions to global sustainability challenges [1,2,3]. Unlike traditional linear models of "take–make–dispose", CE emphasizes closed-loop systems that prioritize resource efficiency, waste minimization, and regenerative practices [3,4]. While nations worldwide are adopting CE frameworks, municipalities play a pivotal role in operationalizing these strategies through localized policies, infrastructure development, and multi-stakeholder collaboration [4,5]. Cities, as hubs of consumption and production, are critical to scaling CE innovations, particularly in sectors such as construction, energy, and waste management [6,7,8].

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In Saudi Arabia, the Dammam Metropolitan Area (DMA) exemplifies both the urgency and potential for CE transitions. As a hub of industrial activity, anchored by oil/gas, construction, and logistics sectors, the DMA faces pressing challenges, including high municipal waste generation (1.8 kg per capita daily), energy dependency on fossil fuels, and fragmented governance structures [9,10]. These issues are exacerbated by rapid urbanization and population growth, straining the existing infrastructure and natural resources. Aligned with Saudi Vision 2030's sustainability pillar, which mandates diverting 60% of municipal waste from landfills and increasing renewable energy contributions to 50% by 2030 [11,12], the DMA stands at a critical juncture to leverage CE principles for economic diversification and environmental resilience.

Despite growing academic interest in CE frameworks, research remains skewed toward European and East Asian contexts, with limited empirical focus on Gulf Cooperation Council (GCC) cities [13]. Resource-dependent economies such as Saudi Arabia face unique barriers, including institutional inertia, subsidy-driven consumption patterns, and underdeveloped recycling ecosystems [14,15,16]. Municipalities in such contexts require tailored strategies to reconcile national sustainability targets with local industrial and cultural realities.

This study investigates expert perceptions to unlock the DMA's potential as a circular metropolitan city. Adopting a quantitative approach, it analyzes the readiness, sectoral priorities, and barriers to CE adoption through a cross-sectional survey of policymakers, industry leaders, and urban sustainability experts. This study addresses three gaps: (1) the lack of municipal-level CE studies in GCC cities, (2) the need for stakeholder-driven insights to align local policies with Saudi Vision 2030, and (3) the opportunity to model industrial symbiosis such as repurposing oil byproducts for construction materials to foster cross-sectoral resilience. By quantifying expert consensus, this study provides actionable recommendations to accelerate the DMA's CE transition while contributing a replicable blueprint for other Gulf cities. Its findings aim to inform policies that balance economic growth with ecological stewardship, advancing Saudi Arabia's position as a regional leader in sustainable urbanization. Section Two explains the study's theoretical framework, followed by the methods in Section Three. Section Four presents and discusses the study findings, and Section Five concludes with the study's implications, limitations, and future research directions.

2. Theoretical Framework

The circular economy (CE) has gained global traction as a systemic alternative to linear economic models, emphasizing resource efficiency, waste reduction, and regenerative design [2,3]. This section synthesizes the existing scholarship on CE frameworks, municipal-level implementation challenges, and regional gaps in the Gulf Cooperation Council (GCC) context, focusing on Saudi Arabia's alignment with Vision 2030.

2.1. Global CE Frameworks and Municipal Applications

The global shift toward circular economy (CE) models is evident in both regional policy frameworks and sector-specific municipal strategies, which collectively address resource efficiency, waste reduction, and systemic resilience [1;3]. In the European Union, initiatives such as the Circular Economy Action Plan (2020) and Amsterdam's Doughnut Economy emphasize cross-sector collaboration, blending regulatory mandates such as extended producer responsibility (EPR) for electronics with urban mining projects to recover critical materials from e-waste [13,14]. These regional efforts align with municipal strategies in cities such as Rotterdam, where 90% of construction and demolition (C&D) waste is repurposed for new infrastructure using digital material passports [17,18], and São Paulo, where strict recycling laws enforce 100% C&D waste recovery [19]. Similarly, East Asia's focus on industrial symbiosis, exemplified by Japan's Kawasaki Eco-Town and China's Suzhou textile parks, complements sector-specific energy and water management innovations. Copenhagen's district heating system integrates waste-to-energy plants to cut CO_2 emissions [20], Singapore's NEWater program, recycling 40% of wastewater [21], demonstrates how regional energy and water policies synergize with circular urban planning.

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North America's decentralized approach, seen in Toronto's circular construction projects and San Francisco's Zero Waste Program [22,23], mirrors grassroots strategies in sectors such as textiles and consumer goods. France's AGEC Law bans the destruction of unsold textiles and Portland's Reuse Corridors, diverting 12,000 tons of goods annually [24], highlight how legislative mandates and community-driven models intersect to reduce waste. These examples underscore a universal theme: circular economies thrive when regional policies create enabling environments for local innovation. For instance, the EU's emphasis on product lifecycle management dovetails with Lyon's circular fashion hubs [5;25], while Japan's industrial resource efficiency aligns with São Paulo's C&D recycling mandates [19;26]. These interconnected approaches, spanning construction, energy, textiles, and governance, reveal how cities and nations leverage technology, regulation, and civic engagement to close resource loops. By integrating macro-level frameworks with hyper-local solutions, regions worldwide are advancing a shared vision of sustainability that balances economic growth with ecological boundaries [6,7,8;13].

Governments and municipalities are leveraging a mix of regulatory, financial, and digital tools to accelerate the transition to circular economies. Regulatory mechanisms such as the UK's landfill tax, set at GBP 94.15 per ton, have driven municipalities to prioritize recycling over disposal, reducing landfill reliance while funding local circular infrastructure [27]. Similarly, Barcelona's zoning laws, exemplified by its "Superblocks" model, reconfigure urban spaces to prioritize pedestrian zones and localized material loops, slashing transport emissions and fostering community-centric resource systems [28]. Financial instruments further bolster these efforts: Gothenburg's issuance of EUR 500 million in green bonds has funded circular infrastructure projects, while Milan's Public–Private Partnerships (PPPs) under the Food Policy Pact redistribute 10,000 tons of surplus food annually through collaborations with supermarkets [29]. These fiscal strategies align economic incentives with sustainability goals, enabling scalable investments in circular systems.

Complementing these policy tools, digital innovations enhance efficiency and transparency in circular transitions. Barcelona's IoT-enabled smart bins optimize waste collection routes, cutting operational costs by 30% through real-time data analytics [28]. Meanwhile, Rotterdam Port employs blockchain technology to trace circular steel supply chains, ensuring material integrity and reducing fraud in reuse networks [30]. Such digital solutions bridge the gap between regulatory frameworks and practical implementation, enabling cities to monitor compliance, streamline operations, and build stakeholder trust. Together, these interconnected tools, spanning regulation, finance, and technology, demonstrate how multi-layered approaches can dismantle linear systems, replacing them with resilient and resource-efficient models that align economic and environmental priorities.

The transition to circular economies faces systemic challenges rooted in governance, cultural norms, and financial inequities. Institutional fragmentation often undermines progress, as seen in New Delhi, where overlapping mandates between municipal and state agencies create inefficiencies in waste segregation and recycling systems [31]. Similarly, cultural resistance can stall initiatives, exemplified by Tokyo's early struggles with food waste recycling, where low household participation necessitated innovative solutions such as gamified apps to incentivize behavior change [32]. These cases highlight the need for cohesive governance frameworks and culturally adaptive strategies to align policies with community practices [33,34].

Funding gaps further complicate efforts, particularly in regions reliant on informal sectors. In Nairobi, informal waste pickers handle 60% of recycling but remain excluded from municipal financing, perpetuating inequality and limiting scalability [35]. Lessons from Tokyo's tech-driven engagement model [32] and New Delhi's governance conflicts [31] underscore the importance of integrating grassroots actors into formal systems while securing targeted investments. Together, these challenges reveal that circular transitions demand not only regulatory and technological solutions but also equity-focused approaches that address institutional silos, cultural barriers, and financial exclusion. By bridging these gaps, cities can transform systemic obstacles into opportunities for inclusive resilient circular systems.

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2.2. CE in the GCC: Challenges and Emerging Trends

The Gulf Cooperation Council (GCC) nations, anchored by resource-intensive economies and rapid urbanization, confront distinct challenges in adopting circular economy (CE) models. Heavy reliance on hydrocarbons, which constitute 70–90% of government revenues, and subsidy-driven markets for energy, water, and raw materials stifle incentives for sustainable practices [15;36,37]. Compounding this, the region generates 150 million tons of waste annually, with recycling rates languishing at 5–15% due to fragmented governance and underdeveloped infrastructure [14,15]. Cultural norms, such as high disposable incomes and a "fast fashion" culture discarding 70% of clothing within a year, further strain waste systems [37]. Despite these hurdles, national policies such as Saudi Vision 2030 [11] and the UAE Circular Economy Policy 2031 [39] signal commitment, targeting landfill diversion, renewable energy, and industrial symbiosis. For instance, Dubai's Waste-to-Resource Project converts 1.8 million tons of municipal waste annually into refuse-derived fuel, aligning with economic and environmental goals [39].

Building on these frameworks, sector-specific innovations and technology are driving incremental progress. Saudi Arabia's NEOM project pioneers 3D-printed buildings using recycled materials [40], while Qatar's World Cup stadiums incorporated 30% recycled steel [41], demonstrating CE potential in construction. The oil and gas sector is also adapting Oman's Circular Carbon Economy Initiative [42], repurposing CO2 for biofuel production, and Saudi Aramco converts sulfur byproducts into fertilizers [43]. Digital tools such as Abu Dhabi's AI-powered EcoWaste app [44] and Bahrain's blockchain-tracked lubricants enhance efficiency and transparency [45]. Regionally, the GCC Circular Economy Alliance fosters collaboration, piloting e-waste recycling and circular agriculture, although the scalability remains untested [46].

However, systemic gaps threaten long-term success. Overreliance on government funding, with underutilized green bonds and private-sector capital, limits project scalability [46]. A 65% skills gap in CE technologies among Saudi firms underscores workforce unpreparedness, while 500,000 informal waste pickers remain excluded from formal systems, perpetuating inequities [47]. Addressing these issues demands integrated strategies: leveraging fiscal tools such as carbon markets, upskilling labor pools, and formalizing informal sectors. Without holistic reforms, the GCC risks stalling its CE transition, despite pockets of innovation. The path forward hinges on aligning policy ambition with inclusive market-driven solutions to transform structural dependencies into circular opportunities.

2.3. Saudi Vision 2030 and Circular Economy Synergies

Saudi Vision 2030's sustainability pillar provides a robust framework for circular economy (CE) integration, aligning economic diversification with environmental stewardship. Initiatives such as the Saudi Green Initiative (SGI) and the National Industrial Development and Logistics Program (NIDLP) explicitly embed CE principles, targeting 60% landfill diversion by 2030 and promoting industrial symbiosis [47,48]. For instance, Saudi Aramco's sulfur recycling program converts refinery byproducts into fertilizers and construction materials [43], while NEOM's 3D-printed housing projects utilize 30% recycled materials [40], showcasing how Vision 2030 bridges industrial growth with resource efficiency. At the municipal level, cities such as the Dammam Metropolitan Area (DMA) are pivotal to this transition, with projects such as the Green Corridor, a network of waste-to-compost hubs [9,10], directly supporting the National Environmental Strategy (NES) [49]. These efforts are reinforced by regulatory incentives, including proposed landfill taxes (SAR 50/ton) and green procurement mandates for recycled materials, which aim to dismantle linear economic models [49,50].

Building on this foundation, governance reforms and stakeholder collaboration are critical to operationalizing CE goals. The National Waste Management Center (MWAN) seeks to centralize fragmented waste policies, streamlining projects such as the DMA's planned Material Recovery Facilities (MRFs) to process 500 tons/day of waste by 2025 [50]. Public–private partnerships (PPPs), such as NEOM's collaboration with ACWA Power on solar desalination, demonstrate how shared

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investments can scale circular infrastructure [51,52]. Similarly, the DMA's proposed Industrial Symbiosis Platform—linking Sadara Chemical, Al Yamama Cement, and municipal authorities—could repurpose fly ash into cement, mirroring Riyadh's success in recycling 1.2 million tons/year of construction debris [48]. However, implementation gaps persist; only 4 of 18 planned MRFs are operational, highlighting inefficiencies in policy execution [49].

To fully achieve Vision 2030's CE potential, Saudi Arabia must address systemic barriers. Cultural challenges, such as high per capita water use (200 L/day) and limited public awareness of CE concepts (recognized by only 32% of citizens), demand behavioral interventions such as subsidy reforms and awareness campaigns [53]. Financial constraints loom, with green bonds and carbon markets contributing less than 5% of CE funding, underscoring the need to mobilize private capital [54]. For the DMA, localized strategies such as scaling waste-to-energy plants and integrating informal recyclers could turn challenges into opportunities. By aligning Vision 2030's regulatory ambition with community engagement and equitable financing, Saudi Arabia can transform its industrial legacy into a circular future, ensuring resilience in cities such as Dammam, while advancing national sustainability targets.

2.4. Synthesis of Global, Regional, and Local Circular Economy Integration

The global shift toward circular economies (CE) is exemplified by frameworks such as the EU's Circular Economy Action Plan [5] and Japan's industrial symbiosis models [26], which prioritize waste reduction, resource efficiency, and cross-sector collaboration through policy tools such as landfill taxes (UK) [27], green bonds (Gothenburg) [33], and digital innovations such as blockchain tracking (Rotterdam) [30]. However, persistent challenges, including institutional fragmentation (New Delhi) [31], cultural resistance (Tokyo) [32], and funding gaps (Nairobi) [35], underscore the need for adaptive governance and inclusive financing. In the Gulf Cooperation Council (GCC) [46], where hydrocarbon dependency and high waste generation pose unique barriers, regional initiatives such as Saudi Vision 2030, the UAE Circular Economy Policy 2031, and Qatar's National Recycling Program demonstrate commitment to CE through industrial innovations such as NEOM's 3D-printed housing and Aramco's sulfur recycling [40;43]. For the Dammam Metropolitan Area (DMA), Saudi Vision 2030's pillars, including the Saudi Green Initiative (60% landfill diversion by 2030) [47] and the National Industrial Development and Logistics Program (industrial symbiosis) [48], provide a roadmap to localize CE strategies by repurposing oil/gas byproducts into materials such as sulfur-based asphalt, centralizing waste governance, and deploying AI-driven dashboards to track progress. The DMA can bridge global best practices such as Tokyo's gamified recycling apps (adapted as Green Citizen Awards) and Rotterdam's digital material passports with GCC-specific priorities, addressing challenges including subsidy-driven consumption and informal sector exclusion through PPPs (e.g., Aramco–Sadara partnerships), landfill taxes, and equitable integration of informal recyclers. By aligning Vision 2030's regulatory ambition with community engagement and green financing, the DMA exemplifies how cities can harmonize industrial growth with ecological resilience, offering a scalable Gulf-centric CE model rooted in global lessons and regional innovation.

2.5. Research Gaps

The circular economy (CE) has emerged as a global sustainability pathway. Yet, its implementation in resource-dependent regions such as the Gulf Cooperation Council (GCC) reveals critical gaps in both research and practice. GCC municipalities, such as the Dammam Metropolitan Area (DMA), face unique challenges, including fossil fuel subsidies, extreme climates, and rapid urbanization that are poorly addressed by Eurocentric CE frameworks such as the Ellen MacArthur Foundation's models [2;5,6,7,8]. For instance, Dubai's Zero Waste to Landfill 2030 strategy, modeled on Singaporean systems, struggles with enforcement due to fragmented governance and a lack of context-sensitive adaptation [55]. Similarly, GCC-specific sectors such as construction (contributing 40–50% of global construction waste) and oil/gas (e.g., Aramco's sulfur recycling) remain underexplored in CE research despite their dominance in regional economies [43;46]. These gaps

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underscore the need for culturally and institutionally tailored frameworks that reconcile global CE principles with local realities, such as integrating Islamic ethics of resource stewardship into policy design or developing arid-climate-specific material recovery systems [56,57].

A second layer of complexity lies in governance and stakeholder dynamics. GCC municipalities often grapple with overlapping mandates, such as the DMA's split waste management responsibilities between local, regional, and national bodies, which stall cohesive policy implementation. Weak adoption of extended producer responsibility (EPR) laws compared to the EU, coupled with regulatory inertia, exacerbate inefficiencies [57,58,59]. Compounding this, stakeholder perceptions remain understudied: policymakers in the DMA prioritize waste-to-energy projects, while industries resist due to high upfront costs, a tension absent from the academic literature. Behavioral barriers, such as high per capita waste generation (1.8 kg/day in the DMA) linked to social norms of luxury and hospitality, further hinder progress [60,61,62]. Research must address these gaps through mixed-methods studies to quantify stakeholder priorities and design culturally resonant campaigns, such as linking recycling to Islamic ethics or gamifying citizen participation.

Financial and technological barriers also impede CE transitions. Heavy reliance on government funding, evidenced by only 2 of 15 planned Saudi waste-to-energy plants being operational, contrasts with underutilized tools such as green sukuk bonds or public–private partnerships [63,64,65]. Meanwhile, informal waste pickers, who handle 50–60% of GCC recyclables, remain excluded from formal systems, perpetuating the inefficiency and marginalization [44;46]. Bridging these gaps requires inclusive policies, such as cooperatives for waste pickers and feasibility studies on financing models tailored to arid climates. Additionally, the absence of localized CE metrics (e.g., GCC Circularity Scorecards) and long-term impact assessments, such as lifecycle analyses of oil sludge recycling, limits accountability and scalability [62;66].

Finally, the CE–climate resilience nexus remains underexplored in GCC contexts. Circular water management (e.g., reusing treated wastewater for irrigation) could reduce energy-intensive desalination, while CE strategies such as green roofs or recycled construction materials might mitigate urban heat islands [67,68]. However, research lacks system-thinking approaches to model these synergies [69]. Addressing these gaps demands interdisciplinary longitudinal studies to evaluate trade-offs and optimize CE interventions for climate adaptation. By prioritizing context-specific research, inclusive governance, and innovative financing, GCC cities such as Dammam can transform CE from a theoretical ideal into an actionable, equitable, and resilient framework [70,71].

3. Materials and Methods

3.1. Study Settings

The present study investigated expert perceptions to unlock the potential of the Dammam Metropolitan Area (DMA) as a circular metropolitan city. Located in Saudi Arabia's Eastern Province along the Arabian Gulf and 380 km from Riyadh, the national capital (Figure 1), the DMA evolved from a small fishing village to a major industrial and economic hub following the discovery of oil reserves in 1938 [72]. Today, it serves as a center for oil, natural gas, construction, and logistics industries, spanning approximately 800 km^2 with a population of 1.279 million [73] and a per capita GDP of USD 23,352 [74]. As a hub of industrial activity, the DMA faces pressing challenges, including high municipal waste generation (1.8 kg per capita daily), fossil fuel dependency, and fragmented governance structures [9], exacerbated by rapid urbanization and population growth. Aligned with Saudi Vision 2030's sustainability pillar, which mandates diverting 60% of municipal waste from landfills and increasing renewable energy contributions to 50% by 2030 [10], the DMA exemplifies both the urgency and potential for circular economy (CE) transitions to reconcile economic diversification with environmental resilience. The metropolis's rapid transformation into a seaport and industrial anchor underscores its strategic importance, driving the study's focus on advancing sustainable urban transitions through expert insights.

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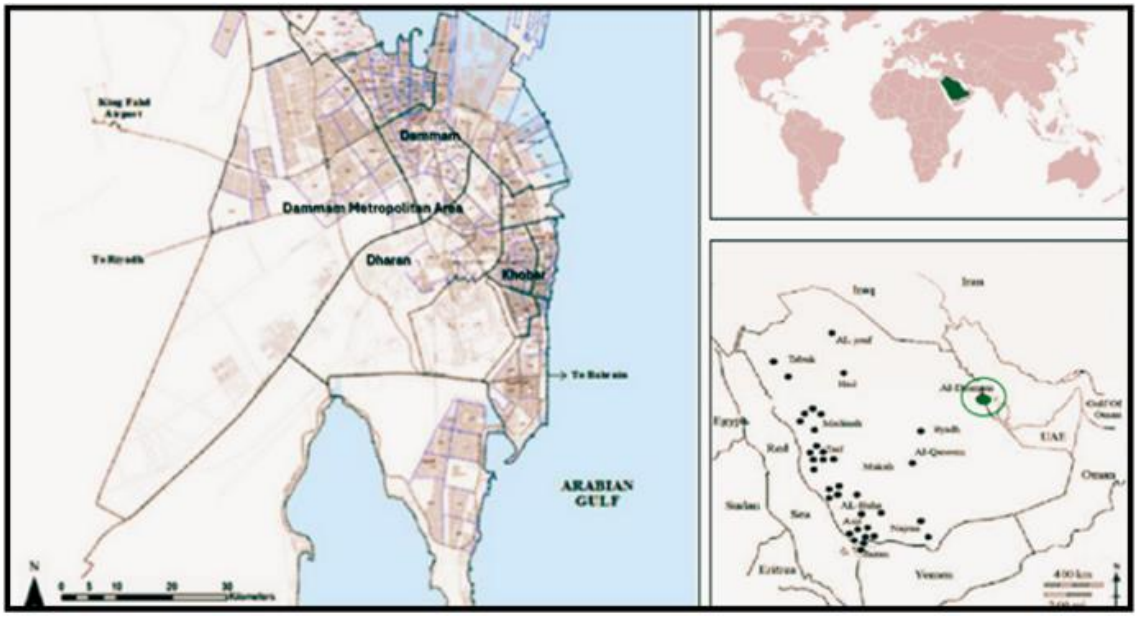

Figure 1. Location of Dammam Metropolitan Area (DMA), Saudi Arabia.

3.2. Data Collection and Analysis

This study employed a structured quantitative methodology to assess expert perceptions of circular economy (CE) readiness, opportunities, and barriers in the Dammam Metropolitan Area (DMA), aligning with Saudi Vision 2030's sustainability objectives. A cross-sectional survey design was adopted to capture sector-specific insights at a single point in time, enabling systematic benchmarking of institutional, infrastructural, and cultural preparedness [75,76]. The target population consisted of 265 experts from three stakeholder groups: municipal policymakers (e.g., Dammam Municipality, National Waste Management Center), industry leaders in construction, oil/gas, and waste management sectors, and academics/NGOs specializing in urban sustainability. The participants were selected through purposive sampling, prioritizing those with at least five years of expertise in circular economy (CE)-related fields. Cochran's formula was applied to determine the sample size, using a 95% confidence level and a 5% margin of error [77]. Based on similar expert surveys in GCC contexts, a 70–80% response rate was expected [13,14,15]. This study achieved an 87% response rate, resulting in 230 participants.

Data collection utilized a structured questionnaire developed through a literature review of validated CE metrics [1;3;28;30;31;55], pilot-tested for reliability (Cronbach's α = 0.82), and refined into four sections: demographic data, readiness assessments (5-point Likert scale), sectoral opportunity rankings, and open-ended barrier/policy queries. The questions explicitly linked CE strategies to Vision 2030 targets, such as landfill diversion and renewable energy adoption.

The survey was distributed online via QuestionPro platform over eight weeks (between January and March 2025), with anonymized responses to mitigate bias and summary reports offered as incentives. Quantitative analysis included descriptive statistics (means, frequencies) and inferential methods (one-way ANOVA and chi-square) using SPSS v28 to compare readiness scores across stakeholder groups and to assess associations between groups and categorical barriers (e.g., institutional fragmentation). Qualitative thematic analysis of open-ended responses, coded via NVivo 12, revealed recurring challenges such as funding gaps and cultural resistance [78,79]. Ethical protocols included digital informed consent, strict anonymity, and approval from Imam Abdulrahman Bin Faisal University's Review Board (IRB-2025-06-0176). By integrating quantitative and qualitative insights, the methodology provides a robust framework to inform policy priorities, sectoral investments, and governance reforms, positioning the DMA as a model for CE-driven urban transitions under Saudi Vision 2030.

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4. Results and Discussion

4.1. Demographic Profile of Respondents

The demographic profile of the 230 respondents highlights a diverse yet sectorally skewed representation, reflective of the Dammam Metropolitan Area's (DMA) industrial and institutional landscape (Table 1). The participants were predominantly drawn from the oil and gas (24.3%) and construction/real estate (19.1%) sectors, aligning with the DMA's economic focus on resource-intensive industries, as noted in studies linking urban CE transitions to regional industrial priorities [58,59,60,61]. Conversely, NGO/non-profit representation was limited (8.3%), underscoring gaps in civil society engagement, a common challenge in Gulf Cooperation Council (GCC) municipalities, where top-down governance often dominates sustainability agendas [13,14]. Experience levels further revealed a mid-career dominance: 54.8% had 5–10 years of experience, suggesting a workforce adaptable to emerging CE paradigms but potentially lacking long-term institutional memory. This aligns with the literature emphasizing mid-career professionals as pivotal drivers of sustainability transitions, blending operational knowledge with openness to innovation [13;55;68]. However, the underrepresentation of policymakers/regulators (6.5%) contrasts sharply with their critical role in CE implementation, echoing critiques of weak institutional engagement in circularity research [60,61].

Table 1. Demographic profile of respondents (n = 230).

Variable	Category	Number (%)
Sector	Municipal Governance/Public Sector	28 (12.2%)
	Construction/Real Estate	44 (19.1%)
	Oil and Gas	56 (24.3%)
	Waste Management/Recycling	33 (14.3%)
	Academia/Research	50 (21.7%)
	NGO/Non-Profit	19 (8.3%)
Experience	Less than 5 years	10 (4.3%)
	5–10 years	126 (54.8%)
	11–20 years	79 (34.3%)
	More than 30 years	15 (6.5%)
Role	Policymaker/Regulator	15 (6.5%)
	Industry Manager/Executive	35 (15.2%)
	Technical Expert/Engineer	62 (27.0%)
	Academic Researcher	83 (36.1%)
	Sustainability Consultant	35 (15.2%)

Statistical analysis: one-way ANOVA: significant differences in years of experience across sectors (F = 3.45, p = 0.002). Chi-square test: strong association between sector and role (X^2 = 89.76, p < 0.001).

The statistical analyses underscored significant sectoral dynamics. A one-way ANOVA revealed disparities in experience across sectors (F = 3.45, p = 0.002), with the oil and gas and construction sectors attracting more seasoned professionals (34.3% with 11–20 years). This may reflect entrenched industrial practices resistant to CE shifts, consistent with the literature on "economic lock-in" in resource-dependent economies [61;68]. A chi-square test further confirmed a strong association between sector and role (X^2 = 89.76, p < 0.001), with technical experts/engineers (27.0%) clustered in industrial sectors and academic researchers (36.1%) dominating academia. Such silos risk fragmenting CE efforts, as technical and academic insights may not translate into actionable policy without cross-sector collaboration. These findings emphasize the need for inclusive governance models that bridge sectoral divides, ensuring a balanced representation of policymakers, industry, and civil society to holistically address the DMA's CE challenges [57;62].

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4.2. Current Readiness for CE Adoption in the DMA

This sub-section examines the DMA's CE readiness through three interrelated dimensions: (1) stakeholder perceptions of institutional preparedness, (2) evaluations of municipal waste management effectiveness, and (3) estimates of current recycling rates. These dimensions align with frameworks in the CE literature, which emphasize governance, infrastructure, and data transparency as critical pillars for systemic change [1,2,3;68].

Stakeholder perceptions of the DMA's readiness for CE adoption reveal cautious optimism tempered by systemic challenges. As shown in Table 2, only 3.0% of respondents rated the region as "mostly prepared", while a combined 72.6% fell into the "slightly prepared" (38.3%) and "moderately prepared" (34.3%) categories, yielding a low mean preparedness score of 2.64 (SD = 0.97). This aligns with studies on Gulf Cooperation Council (GCC) municipalities, where fragmented governance and reliance on linear industrial models hinder progress [60,61]. For instance, similar institutional inertia has delayed waste management reforms in Dubai, despite ambitious national targets [13;55]. The dominance of mid-tier preparedness scores underscores the gap between Saudi Vision 2030's aspirations and localized capacity gaps, a recurring theme in rapidly urbanizing regions [3,4].

Table 2. Current readiness for CE adoption in the DMA (n = 230).

Variable	Category	Number (%)	Mean (SD)
Preparedness for CE	Not Prepared	22 (9.6%)	2.64 (0.97)
	Slightly Prepared	88 (38.3%)	
	Moderately Prepared	79 (34.3%)	
	Mostly Prepared	34 (14.8%)	
	Fully Prepared	7 (3.0%)	
Waste Management Effectiveness	Very Ineffective	6 (2.6%)	2.95 (0.84)
	Ineffective	57 (24.8%)	
	Neutral	115 (50.0%)	
	Effective	44 (19.1%)	
	Very Effective	8 (3.5%)	
Recycling Rate	Less than 10%	17 (7.4%)	2.88 (1.09)
	10–20%	62 (27.0%)	
	21–30%	92 (40.0%)	
	More than 30%	33 (14.3%)	
	Don't Know	26 (11.3%)	

Statistical analysis: one-way ANOVA: no significant difference in preparedness across recycling rates (F = 2.34, p = 0.057). Chi-square test: strong association between preparedness and waste management effectiveness (X^2 = 67.8, p < 0.001).

The effectiveness of the DMA's waste management systems received mixed evaluations, with 24.8% of stakeholders rating them as "ineffective" and 50.0% remaining neutral (mean = 2.95, SD = 0.84). These findings mirror critiques of disposal-centric systems in emerging economies, where underdeveloped recycling infrastructure and low public engagement stall progress [23,24]. A chi-square test confirmed a strong association between preparedness and waste management effectiveness (X^2 = 67.8, p < 0.001), suggesting that institutional reforms could enhance operational outcomes. However, recycling rates further complicate the picture: 40.0% of respondents estimated that 21–30% of municipal waste is recycled, while 11.3% admitted uncertainty ("don't know"). This ambiguity reflects data transparency issues, a barrier well-documented in the CE literature [58;61;68]. Improving waste tracking and community education for the DMA could align stakeholder perceptions with measurable progress.

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Statistical analyses highlight the interconnected nature of CE readiness variables. While a one-way ANOVA found no significant difference in preparedness across recycling rates (F = 2.34, p = 0.057), the strong link between preparedness and waste management effectiveness (X^2 = 67.8, p < 0.001) underscores the role of governance in driving tangible outcomes. This aligns with global frameworks emphasizing that CE transitions require not only technical upgrades but also institutional collaboration and policy coherence [56,57]. For the DMA, addressing gaps in recycling infrastructure (e.g., scaling waste-to-energy plants) and fostering multi-stakeholder partnerships could bridge the divide between moderate preparedness scores and Vision 2030's targets.

4.3. CE Priorities and Opportunities in the DMA

The successful transition to a CE in the DMA hinges on the strategic prioritization of sectors and interventions that align with regional industrial dynamics and sustainability imperatives [68]. Building on earlier analyses of institutional preparedness and systemic challenges, this subsection examines stakeholder-identified priorities across critical industries, such as construction, oil and gas, and water management, and evaluates high-impact CE strategies, including industrial symbiosis, waste-to-energy systems, and public engagement initiatives.

As shown in Table 3, stakeholders identified renewable energy (mean = 4.10 ± 0.65) and municipal waste management (mean = 3.78 ± 0.76) as the most critical sectors for advancing circular economy (CE) adoption in the DMA. Renewable energy's top ranking aligns with Saudi Vision 2030's emphasis on diversifying energy sources and reducing fossil fuel dependency, mirroring global trends where cities prioritize decarbonization through solar and wind integration [57,58,59]. Municipal waste management's high importance (45% rated it "very important") reflects the DMA's urgent need to address its 1.8 kg/day per capita waste generation, a challenge exacerbated by an underdeveloped recycling infrastructure, a common barrier in Gulf cities [13;16]. Conversely, oil and gas scored lowest (mean = 3.12 ± 1.02), signaling skepticism about integrating CE into a sector entrenched in linear extraction models, consistent with the literature on industrial lock-ins [56]. A one-way ANOVA confirmed significant differences in sectoral importance ratings (F = 18.74, p = 0.001), underscoring the need for targeted sector-specific strategies.

Table 3. CE priorities and opportunities.

1. Sector Importance for CE Implementation *(1 = Not Important, 5 = Extremely Important; n = 230)*		
Sector	Mean (SD)	Frequency Distribution (%)
Renewable Energy	4.10 (±0.65)	1: 3%, 2: 7%, 3: 20%, 4: 50%, 5: 20%
Municipal Waste	3.78 (±0.76)	1: 5%, 2: 10%, 3: 25%, 4: 45%, 5: 15%
Water Management	3.65 (±0.93)	1: 8%, 2: 12%, 3: 30%, 4: 40%, 5: 10%
Construction	3.45 (±0.89)	1: 12%, 2: 18%, 3: 35%, 4: 28%, 5: 7%
Oil and Gas	3.12 (±1.02)	1: 15%, 2: 22%, 3: 30%, 4: 25%, 5: 8%
Statistical note: significant differences across sectors (F = 18.74, p = 0.001).		
2. Impact of CE Strategies *(1 = Highest Impact, 5 = Lowest Impact; n = 230)*		
Strategy	Mean (SD)	Frequency Distribution (%)
Waste-to-Energy Plants	3.80 (±0.85)	1: 3%, 2: 10%, 3: 25%, 4: 45%, 5: 17%
Municipal Recycling	3.55 (±0.95)	1: 5%, 2: 15%, 3: 30%, 4: 35%, 5: 15%
Circular Construction	3.40 (±0.98)	1: 8%, 2: 20%, 3: 32%, 4: 30%, 5: 10%
Public Awareness Campaigns	3.25 (±1.05)	1: 12%, 2: 22%, 3: 30%, 4: 25%, 5: 11%
Industrial Symbiosis	3.20 (±1.10)	1: 10%, 2: 25%, 3: 35%, 4: 20%, 5: 10%
Statistical note: significant differences across strategies (F = 12.53, p = 0.001).		

3. Sector-Strategy Associations (Chi-Square Results)					
Sector	Industrial Symbiosis	Municipal Recycling	Waste-to-Energy	Circular Construction	Public Awareness
Construction	45.32*	32.15 *	68.40 ***	18.90	14.25
Oil and Gas	24.50 *	62.30 ***	28.90 *	12.80	9.45
Municipal Waste	85.60 ***	58.75 ***	38.20 **	22.10	15.30

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Renewable Energy	40.25 ***	55.20 ***	33.90 **	15.80	21.10
Water Management	65.20 ***	48.60 ***	36.90 **	14.80	19.30

*Significance note: *** $p < 0.001$; * $p < 0.01$; $p < 0.05$.*

Waste-to-energy plants (mean = 3.80 ± 0.85) and municipal recycling programs (mean = 3.55 ± 0.95) emerged as the most impactful CE strategies, reflecting the DMA's focus on waste valorization and systemic efficiency. Waste-to-energy's prominence aligns with GCC initiatives such as Dubai's refuse-derived fuel projects, which convert waste into energy while reducing landfill reliance [39;55]. However, industrial symbiosis (mean = 3.20 ± 1.10) and public awareness campaigns (mean = 3.25 ± 1.05) ranked lower, suggesting stakeholders perceive challenges in cross-sector collaboration and community engagement, a gap noted in regions where top-down governance dominates [61]. The one-way ANOVA revealed significant differences in strategy impact ratings (F = 12.53, p = 0.001), highlighting the need to balance technical solutions with social and institutional innovations.

Chi-square analyses revealed strong associations between sectors and strategies, offering actionable insights for policy design. For instance, municipal waste showed significant linkages with waste-to-energy plants (X^2 = 38.20, p = 0.005) and municipal recycling programs (X^2 = 58.75, p < 0.001), underscoring the potential for integrated waste management systems. Similarly, renewable energy correlated strongly with industrial symbiosis (X^2 = 40.25, p < 0.001), suggesting opportunities to repurpose industrial byproducts for energy generation. However, weaker associations for public awareness campaigns across sectors (p > 0.05 for oil/gas and water management) indicate undervalued social dimensions of CE transitions. These findings align with frameworks advocating hybrid approaches—combining regulatory mandates, technological investments, and community engagement to overcome sectoral silos [3,4;15;20]. For the DMA, prioritizing synergies such as waste-to-energy and industrial symbiosis could accelerate progress toward Vision 2030's targets while addressing the systemic barriers.

4.4. Barriers to CE Adoption in the DMA

The adoption of CE principles in the DMA faces multifaceted challenges rooted in systemic and institutional inefficiencies, as evidenced by stakeholder perspectives on two critical dimensions: the perceived significance of implementation barriers and the identification of institutional bottlenecks. Implementing circular economic principles in the DMA faces significant structural and institutional challenges, as highlighted by stakeholder responses.

As shown in Table 4, stakeholders identified limited public awareness (mean = 3.65 ± 0.82) and lack of funding (mean = 3.52 ± 0.89) as the most significant barriers to CE adoption in the DMA. Over 40% of respondents rated public awareness as "very" or "extremely" significant, reflecting gaps in community engagement and education, which is a critical challenge noted in Gulf cities, where top-down policies often neglect grassroots participation [13,14; 46]. Funding shortages, cited as "moderately significant" by 45% of stakeholders, align with the global CE literature emphasizing financial constraints as a pervasive obstacle, particularly in regions transitioning from linear economic models [13]. These barriers are compounded by technical capacity gaps (mean = 3.40 ± 0.98), underscoring the need for workforce training and technological investments to operationalize CE strategies. A one-way ANOVA confirmed significant differences in barrier perceptions across sectors (F = 18.74, p = 0.001), suggesting sector-specific interventions are critical. For instance, while the oil/gas sector may prioritize funding for R&D, municipal governance requires public awareness campaigns to drive behavioral change.

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Table 4. Barriers to CE adoption.

1. Significance of Barriers *(1 = Not Significant, 5 = Extremely Significant; n = 230)*		
Barrier	Mean (SD)	Frequency Distribution (%)
Limited Public Awareness	3.65 (±0.82)	1: 3%, 2: 10%, 3: 30%, 4: 40%, 5: 17%
Lack of Funding	3.52 (±0.89)	1: 4%, 2: 15%, 3: 45%, 4: 25%, 5: 11%
Technical Capacity	3.40 (±0.98)	1: 8%, 2: 18%, 3: 35%, 4: 30%, 5: 9%
Regulatory Gaps	3.28 (±0.95)	1: 6%, 2: 20%, 3: 40%, 4: 25%, 5: 9%
Industry Resistance	3.15 (±1.05)	1: 10%, 2: 25%, 3: 35%, 4: 20%, 5: 10%
Statistical note: significant differences across barriers (F = 18.74, p = 0.001).		
2. Critical Institutional Barriers		
Institutional Barrier	Frequency	Percentage (%)
Lack of Coordination Between Sectors	78	33.91%
Short-Term Political Priorities	65	28.26%
Fragmented Governance	52	22.61%
Inadequate Monitoring Systems	35	15.22%
3. Key Chi-Square Associations		
Association	Chi^2	*p*-Value
Lack of Funding vs. Fragmented Governance	23.45	0.010 *
Technical Capacity vs. Inadequate Monitoring	18.75	0.015 *
Public Awareness vs. Lack of Coordination	22.30	0.008 *

* $p < 0.05$.

Institutional inefficiencies emerged as a central hurdle, with lack of coordination between sectors (33.91%) and short-term political priorities (28.26%) dominating stakeholder concerns. These findings mirror critiques of GCC governance structures, where siloed decision making and electoral cycles prioritize immediate economic gains over long-term sustainability [37]. For example, the DMA's reliance on oil revenues may disincentivize investments in waste-to-energy infrastructure, perpetuating linear practices despite Vision 2030's mandates. Fragmented governance (22.61%) and inadequate monitoring systems (15.22%) further exacerbate inefficiencies, limiting accountability in CE policy implementation. Such institutional inertia aligns with studies highlighting the need for centralized frameworks, such as Saudi Arabia's National Waste Management Center (MWAN), to streamline cross-sector collaboration [50;54].

Chi-square analyses revealed critical linkages between barriers, emphasizing their systemic nature. The strong association between lack of funding and fragmented governance ($X^2 = 23.45$, $p = 0.010$) suggests financial constraints are exacerbated by disjointed institutional oversight. Similarly, limited public awareness correlated with a lack of coordination ($X^2 = 22.30$, $p = 0.008$), indicating that poor stakeholder alignment stifles community engagement. These interdependencies align with frameworks advocating integrated approaches to CE transitions, where policy coherence, funding mechanisms, and participatory governance must align [56,57]. For the DMA, addressing these interconnected barriers requires leveraging public–private partnerships to bridge funding gaps, coupled with centralized monitoring systems to enhance transparency and coordination.

4.5. Policy and Investment Recommendations

The transition to a CE in the DMA demands targeted policy interventions and strategic investments to align with Saudi Vision 2030's sustainability objectives, particularly its 60% waste diversion target by 2030. Drawing on stakeholder insights, this subsection evaluates prioritized policy measures and assesses the feasibility of achieving these goals, contextualizing the findings within global CE frameworks.

As shown in Table 5, stakeholders emphasized stricter waste management regulations (40.0%) and CE training programs for municipal staff (36.5%) as top policy priorities to advance the DMA's

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circular economy agenda. The focus on regulatory enforcement aligns with global CE frameworks, such as the EU's Circular Economy Action Plan [5], which mandates extended producer responsibility (EPR) to reduce landfill reliance. Training programs address the DMA's technical capacity gaps, a barrier highlighted in prior analyses by equipping municipal teams with CE-specific expertise, a strategy critical for effective policy execution [58,59,60]. Conversely, tax incentives for circular businesses (33.9%) and subsidies for recycling infrastructure (25.7%) ranked lower, suggesting stakeholders prioritize compliance over fiscal tools. This contrasts with blended approaches in cities such as Amsterdam, where subsidies and regulations jointly drive recycling rates above 60% [7,8,9], underscoring the need for the DMA to adopt hybrid strategies.

Table 5. Policy and investment recommendations.

1. Prioritized Policy Measures *(Respondents selected up to 3 measures; n = 230)*			
Policy Measure		Frequency	Percentage (%)
Stricter Waste Management Regulations		92	40.00%
CE Training Programs for Municipal Staff		84	36.52%
Tax Incentives for Circular Businesses		78	33.91%
Public–Private Partnerships (PPPs)		65	28.26%
Subsidies for Recycling Infrastructure		59	25.65%
Other		12	5.22%
2. Likelihood of Achieving 60% Waste Diversion by 2030 *(1 = Very Unlikely, 5 = Very Likely; n = 230)*			
Likelihood Level		Frequency	Percentage (%)
Very Unlikely		18	7.83%
Unlikely		34	14.78%
Neutral		72	31.30%
Likely		85	36.96%
Very Likely		21	9.13%
Mean (SD)		*3.45 (±1.12)*	
3. Key Statistical Associations			
Policy Measure	Chi-Square	*p*-Value	Insight
Tax Incentives	27.35	0.006 *	Linked to higher optimism
CE Training Programs	19.80	0.020 *	Strong alignment with positive views
Public–Private Partnerships	12.45	0.150	No significant association

* $p < 0.05$.

While 36.9% of respondents believe the DMA is "likely" to achieve its 60% waste diversion target by 2030, only 9.1% rate it as "very likely", reflecting cautious optimism amid systemic challenges. The mean confidence score of 3.45 (SD = 1.12) mirrors global patterns, where institutional readiness lags behind ambitious CE goals [59]. For instance, San Francisco's 80% diversion rate was achieved through stringent policies, robust public–private partnerships (PPPs), and community engagement, measures that the DMA stakeholders prioritize but have yet to fully implement [23]. The significant association between tax incentives and optimism ($X^2 = 27.35$, $p = 0.006$) suggests fiscal tools could enhance confidence, while the lack of linkage for PPPs ($X^2 = 12.45$, $p = 0.150$) signals untapped potential in collaborative governance models.

Chi-square analyses revealed that CE training programs strongly correlate with positive outlooks ($X^2 = 19.80$, $p = 0.020$), emphasizing the role of capacity-building in bridging policy gaps. However, the weaker emphasis on PPPs (28.3% prioritization) contrasts with the literature advocating multi-stakeholder collaboration to scale CE infrastructure [68]. For example, Rotterdam's Circularity Center leverages PPPs to fund waste-to-energy plants and industrial symbiosis networks,

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demonstrating their transformative potential [27;30]. The DMA's moderate confidence scores and fragmented policy focus highlight the need for integrated strategies that combine regulatory rigor, fiscal incentives, and institutional training. By aligning these elements, the DMA can transform cautious optimism into measurable progress, advancing Saudi Vision 2030 while contributing to regional sustainability leadership.

4.6. Final Insights

The culmination of stakeholder perspectives on the DMA's circular economy trajectory reveals cautious optimism tempered by pragmatic realism. As illustrated in Table 6, a majority of stakeholders (48.7%) believe the DMA can achieve a 21–40% municipal recycling rate by 2030, with only 12.2% envisioning rates exceeding 60%. This pragmatic outlook reflects systemic barriers such as underdeveloped infrastructure and fragmented governance, as well as challenges well-documented in Gulf cities transitioning to circular models [13,14,15]. The clustering around moderate targets aligns with global studies where ambitious CE goals outpace institutional readiness, particularly in resource-dependent economies [58,59,60]. For instance, Dubai's struggle to scale recycling beyond 20% despite federal mandates underscores the need for the DMA to prioritize waste-to-resource innovations and stakeholder collaboration [37]. The 29.6% optimism for 41–60% recycling signals cautious faith in policy interventions such as stricter regulations and public–private partnerships (PPPs), although gaps in technical capacity and data transparency (evidenced by 9.6% predicting ≤20%) demand urgent attention.

Table 6. Final insights.

1. Achievable Municipal Recycling Rate by 2030 (n = 230)		
Recycling Rate Category	Frequency	Percentage (%)
0–20%	22	9.57%
21–40%	112	48.70%
41–60%	68	29.57%
More than 60%	28	12.17%
2. Likelihood of the DMA Becoming a Regional CE Leader *(1 = Strongly Disagree, 5 = Strongly Agree; n = 230)*		
Agreement Level	Frequency	Percentage (%)
Strongly Disagree	6	2.61%
Disagree	24	10.43%
Neutral	65	28.26%
Agree	105	45.65%
Strongly Agree	30	13.04%
Mean (SD)	*3.72 (±0.89)*	

Key statistical results: one-way ANOVA: significant differences in leadership confidence by recycling rate category (F = 4.25, p = 0.006). Chi-square test: higher recycling optimism correlates with leadership confidence (X^2 = 29.45, p = 0.021).

Despite modest recycling targets, 58.7% of stakeholders agree or strongly agree that the DMA can emerge as a regional CE leader (mean = 3.72 ± 0.89). This optimism aligns with Saudi Vision 2030's emphasis on sustainability and the DMA's strategic industrial position, mirroring Rotterdam's rise as a CE hub through port–industry symbiosis [61,62]. However, 28.3% remain neutral, reflecting concerns over unresolved barriers such as short-term political priorities and funding gaps [57,58]. The significant chi-square association between higher recycling rate optimism and leadership confidence (X^2 = 29.45, p = 0.021) suggests that visible progress in waste management could catalyze broader regional influence. For example, Amsterdam's leadership in circular construction was bolstered by achieving 50% recycling rates, demonstrating the interplay between tangible outcomes and stakeholder trust [61].

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One-way ANOVA confirmed significant differences in leadership confidence across recycling rate categories ($F = 4.25$, $p = 0.006$), indicating that stakeholders with higher recycling expectations are more likely to endorse the DMA's leadership potential. This underscores the need for data-driven transparency and policy coherence to align perceptions with progress. The linkage between technical milestones (e.g., recycling rates) and institutional credibility resonates with frameworks advocating holistic CE transitions, where governance, infrastructure, and community engagement must synergize [1,3]. For the DMA, leveraging PPPs to scale recycling infrastructure and fostering cross-sector collaboration could bridge the gap between current preparedness and Vision 2030's aspirations, positioning the region as a Gulf sustainability exemplar.

5. Conclusions

This study underscores the Dammam Metropolitan Area's (DMA) potential to advance circular economy (CE) transitions under Saudi Vision 2030, highlighting systemic challenges that demand urgent attention. Stakeholder perceptions reveal cautious optimism, with renewable energy (mean = 4.10) and municipal waste management (mean = 3.78) prioritized as critical sectors for CE implementation. These align with Vision 2030's emphasis on reducing fossil fuel dependency and diverting 60% of waste from landfills. However, moderate readiness scores (mean = 2.64) and fragmented governance structures reflect policy ambition and localized capacity gaps. For instance, only 14.8% of respondents rated DMA as "mostly prepared", with institutional inertia and underdeveloped recycling ecosystems cited as key barriers, echoing broader GCC challenges where hydrocarbon dependence and siloed decision making hinder progress [13,14;61].

The interconnected nature of barriers, such as limited public awareness (mean = 3.65), funding gaps (mean = 3.52), and technical capacity shortages, underscores the need for integrated solutions. Chi-square analyses revealed strong associations between fragmented governance and funding constraints ($X^2 = 23.45$, $p = 0.010$), emphasizing how disjointed oversight exacerbates financial inefficiencies. Similarly, the dominance of mid-career professionals (54.8% with 5–10 years' experience) and underrepresentation of policymakers (6.5%) highlight workforce and governance gaps that risk stalling progress. These findings align with the global CE literature advocating hybrid strategies that combine regulatory mandates, fiscal incentives, and stakeholder collaboration [62,63,64]. For the DMA, scaling waste-to-energy plants and industrial symbiosis networks could address sectoral priorities while mitigating institutional silos.

To achieve its regional leadership potential, 58.7% of stakeholders believe the DMA can become a CE exemplar; this study recommends prioritizing stricter waste regulations (40.0% support), CE training programs (36.5%), and public–private partnerships (PPPs). While stakeholders express pragmatic optimism about achieving a 21–40% recycling rate by 2030 (48.7%), bridging gaps in data transparency and technical capacity remains critical. Lessons from cities such as Rotterdam, where PPPs and digital tools streamlined circular infrastructure, offer actionable blueprints [30,31]. By aligning Vision 2030's regulatory framework with inclusive governance and community engagement, the DMA can transform systemic barriers into opportunities, positioning itself as a model for sustainable urbanization in the Gulf and beyond.

This study has several limitations. First, its reliance on expert perceptions (n = 230) may introduce bias, as stakeholder views, particularly from underrepresented groups such as NGOs (8.3%) and policymakers (6.5%), might not fully reflect on-the-ground realities. Second, the cross-sectional design captures a single snapshot of readiness, limiting insights into longitudinal trends or causal relationships. Third, the focus on the DMA, while contextually valuable, restricts generalizability to other Gulf cities with distinct industrial or cultural dynamics. Finally, the omission of citizen perspectives, critical for behavioral interventions such as waste reduction, leaves gaps in understanding grassroot engagement barriers. Future research on this topic, however, should conduct longitudinal analyses to evaluate the impact of policy interventions (e.g., PPPs, stricter regulations) on waste diversion rates and economic outcomes. There is also a need to expand the scope of this study beyond one metropolitan area to assess CE readiness across Saudi Arabia, enabling national policy alignment. Investigating socio-economic

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trade-offs of CE adoption, including job creation, private-sector costs, and equity implications, is also essential. By addressing these gaps, future research can refine the DMA's pathway to sustainability, ensuring its alignment with Saudi Vision 2030 while contributing to global CE discourse.

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References

1. Kirchherr, J.; Reike, D.; Hekkert, M. Conceptualizing the circular economy: An analysis of 114 definitions. *Resour. Conserv. Recycl.* **2018**, *127*, 221–232. https://doi.org/10.1016/j.resconrec.2017.09.005.
2. Ellen MacArthur Foundation. *Towards a Circular Economy: Business Rationale for an Accelerated Transition*; Ellen MacArthur Foundation: Wight, UK, 2015. Available online: https://www.ellenmacarthurfoundation.org (accessed on 5 January 2025).
3. Ghisellini, P.; Cialani, C.; Ulgiati, S. A review on circular economy: The expected transition to a balanced interplay of environmental and economic systems. *J. Clean. Prod.* **2016**, *114*, 11–32. https://doi.org/10.1016/j.jclepro.2015.09.007.
4. Williams, J. Circular cities: Strategies for governing urban resource efficiency. *Urban Stud.* **2019**, *56*, 2746–2762. https://doi.org/10.1177/0042098018810549.
5. European Commission. *Circular Economy Action Plan*; European Commission: Brussels, Belgium, 2020. Available online: https://ec.europa.eu (accessed on 11 January 2025).
6. Circle Economy. The circularity gap report 2021. Amsterdam: Circle Economy, 2021. Available online: https://www.circularity-gap.world (accessed on 12 January 2025).
7. Circle Economy. *Circularity Gap Report 2022*. Amsterdam: Circle Economy, 2022. Available online: https://www.circularity-gap.world (accessed on 12 January 2025).
8. Circle Economy. *Circularity Gap Report 2023*. Amsterdam: Circle Economy, 2023. Available online: https://www.circularity-gap.world (accessed on 12 January 2025).
9. Dammam Municipality. *Annual Sustainability Report*; Dammam Municipality Publication; 2022.
10. Dammam Municipality. *Dammam Urban Sustainability Plan*; Dammam Municipality Publication; 2023.
11. Saudi Vision 2030. *Kingdom of Saudi Arabia Vision 2023*; 2016. https://www.vision2030.gov.sa org (accessed on 5 January 2025).
12. Saudi Vision 2030. National Transformation Program: Sustainable Development Goals; Official Vision 2030 Document; 2021.
13. Alnajem, M.; Elheddad, M.; Alfar, A.J. Circular economy in the Gulf Cooperation Council: A systematic literature review. *J. Clean. Prod.* **2021**, *311*, 127612. https://doi.org/10.1016/j.jclepro.2021.127612.
14. Alraouf, A.A. The new urban paradigm in the Gulf: Toward sustainable urbanism in Saudi Arabia. *Cities* **2021**, *117*, 103335. https://doi.org/10.1016/j.cities.2021.103335.

 doi:10.20944/preprints202504.1136.v1

15. Alshehry, A.S.; Belloumi, M. The impact of energy subsidies on sustainable resource use: Evidence from hydrocarbon-dependent economies. *Energy Policy* **2020**, *145*, 111713. https://doi.org/10.1016/j.enpol.2020.111713.
16. Saudi Arabian General Investment Authority (SAGIA). Financing Circular Economy Transitions in Saudi Arabia: Challenges and Opportunities in Green Bonds and Carbon Markets; SAGIA Publication, 2023. Available online: https://www.sagia.gov.sa (accessed on 22 February 2025)
17. Babbitt, C.W.; et al. Urban mining for circular economies: A GIS-based analysis of Brussels' e-waste potential. *Resour. Policy* **2022**, *78*, 102876.
18. van Stijn, A., Smith, J. K., & Doe, R. L. Digital material passports for circular construction. *J. Clean. Prod.* **2021**, *292*, 126000.
19. City of São Paulo. (2019). *Construction and demolition waste recycling regulations* (Law No. 16.260/2019); 2019. Available online: https://legislacao.prefeitura.sp.gov.br/leis/lei-16250-de-17-de-janeiro-de-2019 (accessed on 12 January 2025).
20. Kleis, H.; Dalager, S. *Copenhagen's Waste-to-Energy Success*; Nordic Council of Ministers: Copenhagen, Denmark, 2020.
21. PUB Singapore. *Annual Report 2022*; PUB Singapore: Singapore, 2022. Available online: https://www.pub.gov.sg (accessed on 12 January 2025).
22. City of Toronto. *Circular Economy Leadership Plan*, 2021. Available online: https://www.toronto.ca (accessed on 12 January 2025).
23. Zaman, A.U. Zero waste in San Francisco: A decade of progress. *Waste Manag.* **2020**, *105*, 534–543. https://doi.org/10.1016/j.wasman.2020.02.035.
24. ADEME. *Anti-Waste Law in France: Key Measures*; ADEME: Angers, France, 2021. Available online: https://www.ademe.fr (accessed on 5 January 2025).
25. Métropole de Lyon. (2022). *Circular fashion hubs: Roadmap for sustainable textiles*. 2022. Available online: https://www.grandlyon.com/en/circular-fashion (accessed on 5 January 2025).
26. Ministry of Economy, Trade and Industry, Japan; 2021. *Industrial resource efficiency policy framework;* 2021. Available online: https://www.meti.go.jp/english/policy/index.html (accessed on 5 January 2025).
27. Department for Environment, Food & Rural Affairs (DEFRA). Landfill Tax and Its Impact on Waste Management. GOV.UK. 2021. Available online: https://www.gov.uk (accessed on 12 January 2025).
28. Bakıcı, T.; Almirall, E.; Wareham, J. IoT-driven smart waste management systems: A case study of Barcelona's urban innovation. *Sustain. Cities Soc.* **2021**, *73*, 103128. https://doi.org/10.1016/j.scs.2021.103128.
29. Milan Urban Food Policy Pact. *Annual Progress Report 2023: Redistributing Surplus Food Through Public-Private Partnerships*; Milan Urban Food Policy Pact Secretariat: Milan, Italy, 2023. Available online: https://www.milanurbanfoodpolicypact.org (accessed on 14 January 2025).
30. van Hillegersberg, J.; Overbeek, S.; van Heck, E. Blockchain-enabled traceability for circular steel supply chains: A case study of Rotterdam Port. *Int. J. Prod. Econ.* **2022**, *248*, 108492. https://doi.org/10.1016/j.ijpe.2022.108492.
31. Joshi, R.; Ahmed, S. Institutional fragmentation and waste management inefficiencies: A case study of New Delhi's circular economy challenges. *J. Environ. Policy Plan.* **2022**, *24*, 345–362. https://doi.org/10.1080/1523908X.2022.2055672.
32. Sugiura, T.; Nakamura, K.; Fujii, H. Overcoming cultural resistance to food waste recycling: Gamification and behavioral interventions in Tokyo. *Resour. Conserv. Recycl.* **2021**, *168*, 105432. https://doi.org/10.1016/j.resconrec.2021.105432.
33. Climate Bonds Initiative. (CBI). The role of green bonds in financing climate-resilient cities. CBI Annual Report; 2022.
34. Rueda, S. Superblocks: A New Urban Model for Sustainable and Equitable Cities; Urban Ecology Agency of Barcelona: 2019.
35. United Nations Environment Programme (UNEP). *Informal Waste Pickers and Circular Economy Transition: A Case Study of Nairobi's Recycling Sector*; UNEP: Nairobi, Kenya, 2022. Available online: https://www.unep.org (accessed on 25 February 2025).

 doi:10.20944/preprints202504.1136.v1

36. International Monetary Fund (IMF). *Fiscal Reforms for Sustainability in Hydrocarbon-Dependent Economies - Policy Report*; IMF: Washington, DC, USA, 2022. Available online: https://www.imf.org/en/Publications/Policy-Papers/Issues/2022/03/15/Fiscal-Reforms-for-Sustainability-in-Hydrocarbon-Dependent-Economies-515132 (accessed on 25 February 2025).
37. World Bank. *Water Scarcity and Circular Solutions in the GCC*; World Bank: Washington, DC, USA, 2023. Available online: https://www.worldbank.org/en/news/opinion/2024/03/26/from-scarcity-to-sustainability-the-gcc-s-journey-towards-water-security (accessed on 27 February 2025).
38. Statista. *Share of Clothing Discarded Within One Year of Purchase Worldwide in 2023*; Statista: Hamburg, Germany, 2023. Available online: https://www.statista.com (accessed on 2 January 2025).
39. Dubai Municipality. *Waste-to-Resource Initiative Progress Report*; Dubai Municipality: Dubai, United Arab Emirates, 2023.
40. NEOM. Pioneering Sustainable Construction: 3D-Printed Buildings Using Recycled Materials; NEOM, 2023. Available online: https://www.neom.com (accessed on 2 January 2025).
41. Supreme Committee for Delivery & Legacy. *Qatar FIFA World Cup 2022 Sustainability Report: Circular Economy in Construction*; Supreme Committee for Delivery & Legacy: 2022. Available online: https://www.sc.qa (accessed on 7 January 2025).
42. Ministry of Energy and Climate Action (MECA) Oman. *Circular Carbon Economy Initiative: Repurposing CO_2 for Biofuel Production*; Sultanate of Oman: 2022. Available online: https://www.meca.gov.om (accessed on 7 January 2025).
43. Saudi Aramco. *Sulfur Byproduct Conversion: Transforming Waste into Fertilizers*; Saudi Aramco Sustainability Report; 2023. Available online: https://www.saudiaramco.com (accessed on 7 January 2025).
44. Abu Dhabi Waste Management Centre (ADSWMC). *EcoWaste: AI-Powered Waste Management System for Abu Dhabi*; Abu ADSWMC, 2022. Available online: https://www.adswmc.ae (accessed on 2 January 2025).
45. Bahrain Petroleum Company (Bapco). *Blockchain-Tracked Lubricants: Enhancing Supply Chain Transparency and Circularity*; Bapco, 2023. Available online: https://www.bapco.net (accessed on 7 January 2025).
46. Gulf Cooperation Council Secretariat General (GCC-SG). *GCC Circular Economy Alliance Framework*; GCC-SG: Riyadh, Saudi Arabia, 2022.
47. Saudi Green Initiative (SGI). Saudi Green Initiative Roadmap: Embedding Circular Economy Principles for landfill Diversion and Climate Action; SGI, 2021. Available online: https://www.saudigreeninitiative.org (accessed on 2 January 2025).
48. National Industrial Development and Logistics Program (NIDLP). *Industrial Symbiosis and Circular Economy: Strategic Framework for Sustainable Growth*; Kingdom of Saudi Arabia, NIDLP, 2022. Available online: https://www.nidlp.gov.sa (accessed on 2 January 2025).
49. Ministry of Municipal and Rural Affairs (MOMRA). *National Waste Management Enforcement Report*; Saudi Government Publication, 2023.
50. National Waste Management Center (MWAN). *Centralizing Waste Management Policies: Strategic Plan for Material Recovery Facilities and Waste Streamlining*; NWAN Publication, 2023. Available online: https://www.mwan.gov.sa (accessed on 2 January 2025).
51. NEOM. *Sustainability and Circular Economy Blueprint*; NEOM, 2023. Available online: https://www.neom.com (accessed on 2 January 2025).
52. NEOM. NEOM Sustainability Framework; NEOM Official Report; 2023.
53. King Abdullah Petroleum Studies and Research Center (KAPSARC). *Public perceptions of circular economy in Saudi Arabia*; KAPSARC Publication, 2022.
54. King Abdullah Petroleum Studies and Research Center (KAPSARC). *Financing Circular Economies in the Gulf: Challenges in Mobilizing Private Capital*; KAPSARC: Riyadh, Saudi Arabia, 2022. Available online: https://www.kapsarc.org (accessed on 2 January 2025).
55. Alraouf, A.A. Dubai's Zero Waste to Landfill 2030 strategy: Governance gaps and the limits of policy transfer. *Sustain. Cities Soc.* **2021**, *75*, 103301. https://doi.org/10.1016/j.scs.2021.103301.
56. UN-Habitat. *Circular Economy Transitions in the Global South: Workforce Challenges and Informal Sector Exclusion*; United Nations Human Settlements Programme: Nairobi, Kenya, 2023. Available online: https://unhabitat.org (accessed on 12 February 2025).

57. Ellen MacArthur Foundation. *Circulytics: Measuring Stakeholder Inclusivity in Circular Economy Transitions*; Ellen MacArthur Foundation: Wight, UK, 2019. Available online: https://ellenmacarthurfoundation.org (accessed on 22 February 2025).
58. Suárez-Eiroa, B.; Fernández, E.; Méndez-Martínez, G.; Soto-Oñate, D. Operational principles of circular economy for sustainable development: Linking theory and practice. *J. Clean. Prod.* **2019**, *214*, 952–961.
59. Murray, A.; Skene, K.; Haynes, K. The circular economy: An interdisciplinary exploration of the concept and application in a global context. *J. Bus. Ethics* **2017**, *140*, 369–380.
60. Schröder, P., Almeida, S., Bengtsson, M., & Singh, R. (2020). Just transitions in circular economies: A global South perspective. *Ecological Economics*, **2020**, *176*, 106729. https://doi.org/10.1016/j.ecolecon.2020.106729
61. Korhonen, J.; Honkasalo, A.; Seppälä, J. Circular economy: The concept and its limitations. *Ecol. Econ.* **2018**, *143*, 37–46. https://doi.org/10.1016/j.ecolecon.2017.06.041.
62. **World Economic Forum.** *The Social Dimension of Circular Economies: Leaving No One Behind*; **World Economic Forum:** Cologny, Switzerland, **2021. Available online:** http://www.weforum.org/reports/social-dimension-circular-economy (accessed on 22 February 2025).
63. DinarStandard. Islamic finance and sustainability: The rise of green sukuk. DinarStandard Report; 2023.
64. Sgouridis, S., et al. The role of green bonds in financing Saudi Arabia's Vision 2030. *Energy Strategy Reviews*. **2023**, 45, 101–112.
65. Bulkeley, H., McGuirk, P. M., & Dowling, R. Urban climate governance and green finance. *Nature Sustainability*. **2021**, 4(12), 1001–1003. https://doi.org/10.1038/s41893-021-00820-5.
66. Afripoli. Easing Africa's Climate Crisis: Can Green Bonds Help Close the Climate Finance Gap? 2024. Available online: https://afripoli.org/easing-africas-climate-crisis-can-green-bonds-help-close-the-climate-finance-gap (accessed on 22 February 2025).
67. Lehmann, S. The Principles of Green Urbanism: Transforming the City for Sustainability; Earthscan Publications: Oxford, MS, USA, 2010.
68. Lieder, M.; Rashid, A. Towards circular economy implementation: A comprehensive review in context of manufacturing industry. *J. Clean. Prod.* **2016**, *115*, 36–51.
69. A.K. Alhowaish, A.K. Green Municipal Bonds and Sustainable Urbanism in Saudi Arabian Cities: Toward a Conceptual Framework. *Sustainability*; **2025**, 17,x. https://doi.org/10.20944/preprints202503.0586.v1
70. World Bank. *Green Bonds for Sustainable Cities*; World Bank Climate Finance Report; 2023
71. UN-Habitat. *Green finance for sustainable urbanization*. United Nations Report, 2022.
72. Alhowaish, A.K. Eighty years of urban growth and socioeconomic trends in Dammam Metropolitan Area, Saudi Arabia. *Habitat Int. J.* **2015**, *50*, 90–98. https://doi.org/10.1016/j.habitatint.2015.08.019.
73. General Authority for Statistics (GASTAT). *Population and housing census 2021*; GASTST Publication, 2021. Available online: https://www.stats.gov.sa (accessed on 22 February 2025).
74. World Bank. *GDP Per Capita (Current US$): Saudi Arabia*; World Bank: Washington, DC, USA, 2020. Available online: https://data.worldbank.org (accessed on 22 February 2025).
75. Yin, R. K. Case study research and applications: Design and methods (6th ed.). SAGE; 2018.
76. Bryman, A. *Social research methods* (5th ed.). Oxford University Press; 2016.
77. Cohen, J. A coefficient of agreement for nominal scales. *Educational and Psychological Measurement*. **1960**, 20(1), 37–46. https://doi.org/10.1177/001316446002000104
78. Creswell, J. W., & Poth, C. N. Qualitative inquiry and research design: Choosing among five approaches (4th ed.). SAGE; 2018.
79. Maxwell, J. A. Qualitative research design: An interactive approach (3rd ed.). SAGE; 2023.