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Environmental excellence in Saudi Arabia: Governance, achievements, and strategic opportunities — a systematic review (PRISMA 2020)

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Abstract

Under Vision 2030, Saudi Arabia has rebuilt its environmental governance around the 2020/21 Environment Law, the National Center for Environmental Compliance, the Saudi Green Initiative (SGI), and ISO 14001/EIA alignment. This review sets out that framework, draws together outcomes across biodiversity, air, water, waste, and climate/energy, and flags priority gaps for Vision 2030 and comparable jurisdictions.

The search, conducted to PRISMA 2020 standards, covered Scopus, Web of Science, PubMed, and Google Scholar, supplemented by reference-list and grey-literature screening against a pre-specified PECO frame. All records were screened by the author; a second screener dual-screened a 20% sample. Quality was appraised with JBI checklists, and certainty was rated using a GRADE-informed approach.

Of 3,512 records screened after de-duplication, 78 sources met inclusion criteria, spanning six domains: governance and compliance institutions; biodiversity (protected-area coverage grew from ~4% to 18.1% of land); air quality (~240 stations; declining PM_{2.5}, NO_x, SO₂); water (>200 plants; 100% urban-reuse target); waste (2021 Waste Management Law; 85-90% diversion by 2035-2040); and clean energy/climate (50% renewable electricity by 2030; net-zero by 2060; expanding CCUS/hydrogen). Certainty was moderate for governance, low to moderate for environmental quality (largely government reports), and low for projections.

Vision 2030 has substantially expanded the Kingdom's environmental institutions, laws, and infrastructure, with real progress in protected areas, monitoring, wastewater reuse, and renewables. Still, the evidence base leans heavily on descriptive policy sources, and independent long-term evaluation remains thin. Priorities ahead: independent monitoring and verification, disaggregated outcome data, and replication in comparable arid, hydrocarbon-exporting jurisdictions.

Keywords: Saudi Arabia; Environmental governance; Vision 2030; National Center for Environmental Compliance; Renewable energy transition; Circular Carbon Economy

1. Introduction

Saudi Arabia's approach to environmental management has changed substantially over the past two decades. The

General Environmental Regulation of 2001 marked an early turning point, establishing the Kingdom's first nationwide prohibitions on pollution of air, water, and land [1-3]. Subsequent laws addressed wildlife protection, hunting, the

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trade in endangered species, and waste, progressively widening the conservation toolkit [4, 5]. In 2016, Vision 2030 designated environmental sustainability as a pillar of national development [6], and institutional reform followed shortly thereafter. The Ministry of Environment, Water, and Agriculture (MEWA) received an expanded sustainability mandate that same year, and by 2019 five specialized centers had been established to build capacity across compliance, meteorology, wildlife, vegetation, and waste management [7, 8]. One of these, the National Center for Environmental Compliance (NCEC), became the Kingdom's dedicated regulator, responsible for enforcing standards and carrying out inspections nationwide [9]. Its remit extends from monitoring air, water, and soil quality to issuing environmental permits and verifying that development projects meet national and international requirements [10, 11].

The legislative framework changed correspondingly. A new Environment Law, issued by Royal Decree in July 2020 and effective from 2021, replaced the earlier regulations, tightening pollution controls, updating EIA procedures, and raising penalties for violations [12-15]. Its implementing regulations set detailed limits on emissions, effluent discharges, and hazardous-waste handling, many benchmarked against international guidelines; where a national standard does not yet exist, an EIA may draw on relevant World Bank/IFC or EU criteria [15, 16]. A similar shift is evident in industry, where uptake of ISO 14001 environmental management systems has grown as firms seek to improve compliance and resource efficiency [17-19]. Together, these changes reflect a governance model that is more outward-looking and more reliant on compliance than previously.

Two major programmes have set the agenda for climate and conservation work alongside these legal and institutional changes: the SGI, announced in 2021, and its regional counterpart, the Middle East Green Initiative (MGI) [20-22]. The SGI brings together targets for climate action, pollution reduction, and ecosystem restoration, including planting 10 billion trees domestically, rehabilitating degraded land, and protecting 30% of the country's land and marine area by 2030 [2], consistent with wider commitments such as the "30 by 30" biodiversity pledge. During its 2020 G20 presidency, the Kingdom also launched initiatives on land degradation and a

global research platform for coral-reef conservation [23]. These developments mark a substantial change from Saudi Arabia's earlier image as primarily a hydrocarbon economy, and the policy language has shifted correspondingly, framing environmental action as part of economic diversification rather than a constraint on it [24]. This framing tends to emphasize achievements, such as reduced flaring and emissions and new parks and reserves; however, as discussed later in this review, several of these claims rest primarily on government reporting [25].

Given these developments, an assessment of how Saudi Arabia's environmental compliance landscape has evolved and what has been achieved across its key domains is warranted. This paper presents a systematic review of the literature on environmental compliance in Saudi Arabia, examining governance structures, laws, and implementation outcomes across biodiversity conservation, air and water quality management, waste control, and climate-related measures. By evaluating national efforts against international frameworks such as ISO 14001 and EIA best practice, this review indicates where Saudi Arabia's approach meets or exceeds global benchmarks and where it does not. The review aims to maintain a factual, evidence-based approach throughout documenting the Vision 2030 framework's initiatives and reported outcomes while identifying areas where independent verification, longer-term outcome data, or methodological strengthening of the existing evidence would be beneficial. Progress is neither understated nor overstated; the PRISMA 2020 standard of transparent reporting is applied throughout to the available evidence. The findings offer broader insight into how a resource-rich economy can reshape its environmental governance and align with sustainable development goals within a relatively short period, providing lessons for policymakers and stakeholders beyond Saudi Arabia.

2. Methodology

2.1. Scope and rationale for the review approach

This is a structured narrative review employing a PRISMA 2020-aligned reporting framework, rather than a meta-analytic systematic review of effect estimates. It addresses a broad, multi-domain governance question and draws on descriptive evidence peer-reviewed studies,

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regulatory instruments, and official reports that do not lend themselves to quantitative pooling. The PRISMA 2020 framework was applied to ensure that identification, screening, appraisal, and reporting of this evidence remained transparent and reproducible. A pre-specified PECO frame, a documented search strategy with a last-search date and language restriction, methodological appraisal using the Joanna Briggs Institute (JBI) critical-appraisal checklists for empirical studies, and a structured rubric for grey literature, and a GRADE-informed certainty assessment are reported below, with a completed PRISMA 2020 checklist and flow diagram provided as a companion supplement. A more focused systematic review of the measured impact of the 2020/21 Environment Law on industrial-emission compliance, for example, is identified as a priority direction for future work.

The review was designed and reported in accordance with the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA 2020) 27-item checklist and flow diagram. A completed PRISMA 2020 checklist is provided as a supplementary file (Supplementary Table S1), and the Abstract follows the PRISMA 2020 for abstracts checklist (Supplementary Table S2). The review was not prospectively registered on PROSPERO; a written protocol was prepared prior to screening and is available on reasonable request. Deviations from this protocol are reported in the Limitations section [26, 27] to maintain a transparent and reproducible process. The scope was defined broadly to encompass multiple dimensions of environmental compliance: regulatory frameworks, institutional capacity, monitoring and enforcement mechanisms, and the specific thematic areas of biodiversity, air, water, waste, and climate/energy initiatives.

2.2. Search strategy

The search covered the period from 1 January 2000 through 31 January 2025 (last search executed 31 January 2025), with analytic emphasis on 2015–2024, corresponding to the Vision 2030 reform era, and was limited to English-language sources. Scopus, Web of Science, and PubMed were queried, along with interdisciplinary sources such as Google Scholar, for relevant peer-reviewed articles, review papers, and official reports. Search terms combined keywords such as “Saudi Arabia” AND “environmental compliance” OR “environmental law” OR “environmental policy” OR

“governance” OR “Vision 2030” alongside specific domains (e.g., “biodiversity”, “protected areas”, “air quality”, “water management”, “waste management”, “EIA”, “ISO 14001”, “climate change mitigation”). One example search string was “Saudi Arabia” AND (“environment compliance” OR “environment law” OR “EIA” OR “biodiversity” OR “pollution” OR “ISO 14001”). Reference lists of key articles were also reviewed (snowball sampling) to identify additional sources not captured by the database searches.

2.3. Inclusion criteria

Eligibility was specified a priori using a PECO (Population, Exposure, Comparator, Outcomes) framework. Population: the Kingdom of Saudi Arabia, with secondary inclusion of GCC-wide or Middle East/North Africa (MENA) studies where Saudi-specific data could be extracted. Exposure: environmental governance, legal, regulatory, institutional, monitoring, or implementation interventions (e.g., the 2020/21 Environment Law, NCEC, SGI, EIA procedures, ISO 14001 adoption, the Waste Management Law, energy-transition policies, CCUS, and hydrogen programmes). Comparator: international standards (ISO, WHO, IFC/World Bank, UNEP, IPCC) or pre-reform baseline values, where reported. Outcomes: (a) governance and institutional outcomes (legal coverage, enforcement actions, EIA throughput); (b) environmental quality outcomes (air and water quality metrics, protected-area coverage, biodiversity indicators); (c) policy implementation and emissions outcomes (renewable capacity, energy intensity, waste diversion, CO₂/CH₄ emissions). Study designs: empirical studies (quantitative, qualitative, mixed methods), reviews, official government publications, and reports from international agencies. Time period: 1 January 2000 to 31 January 2025. Language: English. Studies without Saudi-relevant data extractable to the population, conference abstracts without sufficient methodological detail, duplicate datasets, and editorials without primary evidence were excluded, while critical, dissenting, and gap-identifying peer-reviewed literature was included on equal terms with positively framed sources.

2.4. Study selection

Records retrieved from each database were exported and deduplicated using reference-management software. All titles,

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abstracts, and full texts were screened against the eligibility criteria by the author. To assess screening reliability, a second screener (acknowledged in the Acknowledgements and not meeting ICMJE authorship criteria) independently dual-screened a 20% random sample of titles, abstracts, and full texts; disagreements were resolved by discussion. This single-author screening with a partial dual-screening check constitutes a deviation from the strict PRISMA 2020

expectation of independent dual screening of every record and is reported in Section 4 (Limitations). Records excluded at full-text review were logged with reasons (not Saudi-specific, no extractable outcome data, duplicate report of an included study, full text unavailable). The final tally of records identified, screened, excluded with reasons, and included is presented in the PRISMA 2020 flow diagram (Figure 1) [27].

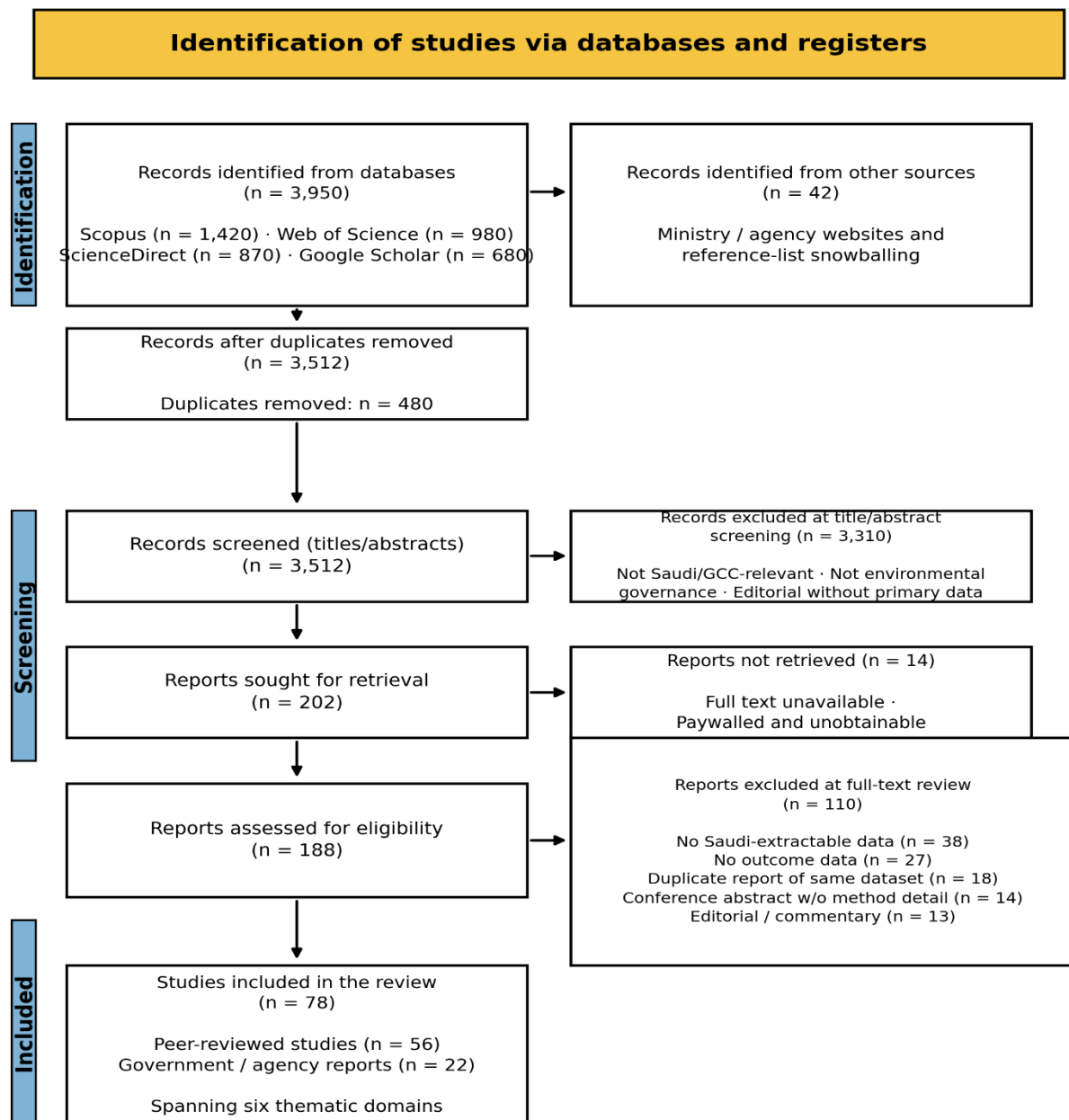


Figure 1. PRISMA flow diagram. Adapted by the author from the PRISMA 2020 flow diagram template [27], reused under the Creative Commons Attribution 4.0 International License (CC BY 4.0); no additional permission was required.

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2.5. Methodological quality and risk of bias assessment

Methodological quality of included empirical studies was appraised using the Joanna Briggs Institute (JBI) critical appraisal checklists matched to study design (cross-sectional, qualitative, mixed methods, text, and opinion, and quasi-experimental, as applicable). Government and international-agency reports were appraised against a structured rubric covering source authority, methodological transparency, currency of data, internal consistency, and triangulation with independent sources. Each source was appraised by the author, and the second screener independently re-appraised the sources in the 20% dual-screening sample; discrepancies were resolved by discussion. Studies were not excluded on quality grounds alone, but quality ratings informed the weight given to individual sources during synthesis and the certainty assessment described below. Risk-of-bias ratings for each included source are summarized in Supplementary Table S3.

2.6. Data extraction and synthesis

A standardized data-extraction form was developed and piloted on five sources prior to full extraction. The following information was extracted from each included source: bibliographic details (author, year, country/setting), study design, time period of data, exposure/intervention described, comparator (where applicable), outcomes reported, key quantitative findings, and the source's stated conclusions. Extraction was performed by the author, and the second screener independently verified extraction for the sources in the 20% dual-screening sample; discrepancies were resolved by discussion. Where multiple reports described the same underlying dataset, the most complete report was used as the primary source. Thematic synthesis organized the findings into six recurring categories: (1) governance reforms and institutions; (2) biodiversity conservation initiatives; (3) air and water quality management; (4) waste management and circular economy; (5) clean energy and climate action initiatives; and (6) outcomes and future opportunities. These themes structure the Results and Discussion that follow [28]. Throughout the synthesis, facts were cross-verified against multiple sources, and points of convergence in the literature were noted. Given the broad scope, discussion was integrated with results, with context and comparisons particularly against

international standards or cases-presented alongside the findings. All statements are supported by citations to the reviewed sources, which are retained in the text for transparency.

2.7. Synthesis and certainty of evidence

Given the heterogeneity of study designs and outcome measures, a quantitative meta-analysis was not appropriate. A narrative thematic synthesis was conducted instead, structured around the six pre-specified domains: (1) governance reforms and compliance institutions; (2) biodiversity and protected areas; (3) air quality; (4) water quality; (5) waste management and circular economy; and (6) clean energy and climate. For each domain, findings were tabulated, compared across sources, and triangulated against international standards or independent measurements where available. Where evidence on a specific outcome was limited, this is stated explicitly rather than obscured. Certainty of the evidence underpinning each domain was rated using a GRADE-informed narrative approach, considering study design and methodological quality, consistency across sources, directness of evidence, precision of reported estimates, and risk of publication bias, with particular attention to the extent to which self-reported government data substituted for independently verified measurements. Each domain was assigned a certainty rating of High, Moderate, Low, or Very Low; ratings and justifications are reported in Section 3.11 (Certainty of Evidence). Selective reporting and other potential reporting biases were considered qualitatively; a formal funnel-plot assessment was not possible given the absence of comparable effect sizes across sources.

The aim throughout was a transparent, reproducible synthesis of the evidence on Saudi Arabia's environmental compliance progress, encompassing both reported achievements and remaining gaps. The PRISMA 2020 framework standardized the identification, screening, appraisal, and reporting of this evidence; its limitations are discussed in Section 4 (Limitations). The sections that follow present the review's consolidated results by theme and discuss their implications for Saudi Arabia's efforts and leadership in environmental protection.

3. Results and discussion

The rules, guidelines, and initiatives cited below are illustrative, not exhaustive-other relevant tools and

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frameworks exist but fall outside the scope and space of this review. Tables 1 and 2 summarize the key governance reforms discussed in the sections that follow.

Table 1. Summary of Saudi Arabia's environmental governance achievements.

Governance reforms	Description	Key point	References
National Center for Environmental Compliance (NCEC)	Establishment in 2019. NCEC is the primary regulatory body responsible for environmental compliance, overseeing monitoring, permitting, and enforcement. It works to align national practices with ISO 14001 and international frameworks such as those of the EU and World Bank.	It provides a national system for monitoring and evaluating water, air, and soil quality and enforces compliance for waste management and industrial emissions.	[19, 29, 30]
Environment Law (2020/21)	New Environment Law issued in 2020/21, introducing stricter pollution controls, stronger penalties, and enhanced cross-sector coordination in line with Vision 2030.	Provides updated legal guidance on pollution sources and waste discharge and strengthens incentives for industries to adopt ISO 14001 and related environmental management standards.	[20, 31, 32]
Framework for Vision 2030	Vision 2030 is Saudi Arabia's long-term development strategy, which integrates sustainability goals across all sectors. It promotes cross-sector cooperation, strengthened environmental management, and large-scale green initiatives.	Demonstrates significant progress in waste reduction, biodiversity protection, and clean-energy deployment. Includes the launch of the SGI and the expansion of protected natural areas.	[33-36]
Saudi Green Initiative (SGI)	Introduced in 2021, the SGI aims to accelerate large-scale tree planting, rehabilitate degraded ecosystems, and protect biodiversity as part of the Kingdom's long-term sustainability commitment.	Targets the planting of 10 billion trees, advancing global leadership in wetland and tree-cover preservation. Includes extensive mangrove restoration, wildlife corridor development, afforestation, and habitat rehabilitation.	[36, 37]
Air quality control and management	Implemented primarily through the NCEC and supported by the National Center for Meteorology (NCM) through atmospheric monitoring and cloud-seeding programs aimed at reducing dust and pollutant levels.	Air quality management includes a nationwide network of more than 240 monitoring stations showing declining trends in major pollutants such as PM _{2.5} , nitrogen oxides (NO _x), and sulfur dioxide (SO ₂) in major cities.	[38, 39]
Water quality management	National programs focused on improving water quality, expanding wastewater treatment, and increasing treated-water reuse across industrial and agricultural sectors.	Saudi Arabia operates more than 200 water and wastewater treatment plants, covering potable water, industrial water treatment, and sewage/industrial wastewater processing. The Kingdom aims for near-100 percent urban wastewater reuse and is recognized as one of the world's largest producers of desalinated water, ensuring environmental compliance, including alignment with MARPOL pollution-prevention standards.	[3, 20]

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Table 1. Continued.

Governance Reforms	Description	Key Point	References
Waste management and law of circular economy	The Waste Management Law establishes comprehensive regulations for waste segregation, treatment, recycling, and waste-to-energy development, forming the foundation for a national circular-economy transition.	The law targets major reductions in landfill dependence and supports national recycling infrastructure expansion, including large-scale material recovery and processing facilities. It also promotes public-private partnerships (PPPs) to advance recycling, waste-to-energy, and resource-efficient systems.	[9, 40-45]
Clean energy and climate	Saudi Arabia's clean-energy and climate agenda centers on expanding renewable-energy capacity, enhancing energy efficiency, and advancing circular-carbon-economy pathways in line with national sustainability targets.	The Kingdom aims to generate 50 percent of its electricity from renewable energy by 2030 and is expanding utility-scale solar and wind projects such as the Sakaka Solar Plant (300 MW) and other Vision 2030 initiatives. It has also announced a net-zero emissions target for 2060 through the Circular Carbon Economy (CCE) Framework, alongside strengthened methane-reduction and energy-efficiency measures.	[7, 46-50]
Carbon Capture, Utilization, and Storage (CCUS) and hydrogen	National initiatives focused on advancing CCUS technologies, alongside the development of low-carbon and green hydrogen pathways for industrial decarbonization.	The CCE Framework, promoted by Saudi Arabia and endorsed during its G20 presidency, provides the means to reduce, reuse, recycle, and remove carbon emissions, supporting large-scale CCUS deployment and hydrogen production.	[20, 51-54]

3.1. Governance reforms and compliance framework

Governance reform is a theme evident across nearly every source reviewed here, and its scale is substantial. New regulatory bodies and revised legal frameworks now underpin the broader environmental agenda. The clearest example is the NCEC, established in 2019, which the literature credits with strengthening enforcement [31, 32]. Operating under MEWA, it oversees pollution sources, permitting, and inspections nationwide, reflecting a shift toward more active rule-of-law regulation [29]. By monitoring industrial emissions, effluents, and waste handling directly, it holds facilities to the standards

set out in the Environment Law and its implementing regulations [19, 30]. Early indications are encouraging, though largely anecdotal: case studies report that the NCEC's inspections and its requirement for periodic Environmental Compliance Reports have improved adherence to emission limits and accelerated correction of violations [29, 31, 32].

The Kingdom's institutional development extended beyond the NCEC. It also established the National Center for Waste Management (NCWM; Arabic transliteration MWAN, the form used in the center's public communications and Arabic-language regulatory documents, and adopted hereafter) and the National Center for Wildlife (NCW), among others, each

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with a specialized focus. MWAN regulates and supervises waste management activities, licensing operators and promoting circular-economy principles in accordance with new waste legislation [19, 41]. The NCW leads wildlife conservation, manages protected areas, and coordinates biodiversity programs. All of these centers report into an empowered governance hierarchy, comprising inter-ministerial committees and high-level councils, that maintains cross-sector coordination. A notable feature is the integrated nature of this model: rather than siloed efforts, the country has adopted a “One Government” approach in which environment-related mandates across energy, water, agriculture, industry, and municipalities are aligned under the Vision 2030 umbrella. Digital tools reinforce this framework. An online environmental licensing platform now processes permit applications and EIA submissions for developers [55]. The NCEC categorizes projects into three tiers (I, II, III) by potential impact, which determines the depth of assessment required [56]. This risk-based tiering, combined with mandatory Environmental Management Plans for all but the lowest-impact projects, follows established assessment practice and has improved the consistency of reviews. Monitoring has also benefited from technical partnerships: the NCEC collaborates with KAUST on air-quality forecasting and real-time data networks, utilizing supercomputing for pollution forecasts and satellite data for change detection [57]. These reforms are also benchmarked against international norms. The 2020/21 Environment Law and its executive regulations draw on EU and U.S. environmental law, requiring public and private bodies to prevent pollution and remediate after accidents [15]. The penalties specified in the law's appendices, including substantial fines and, in some cases, facility shutdowns, broadly align with international practice. Saudi Arabia is also party to the principal multilateral agreements, including the Paris Agreement, the Convention on Biological Diversity, and MARPOL, and has translated these commitments into national rules [23, 58]. Together, the 2020/21 Environment Law and its implementing regulations establish the framework for pollution control, waste management, and resource conservation [29]. In certain instances, the Kingdom has set standards exceeding international requirements: certain megaprojects, such as NEOM, have committed to applying whichever environmental

standard is more stringent, national or international, thereby establishing new benchmarks for sustainability.

Collectively, this framework provides the basis for the initiatives discussed in subsequent sections. Institutional capacity, including inspector numbers, monitoring frequency, and inter-agency coordination, has grown markedly. These structural reforms, comprising new laws, new agencies, and stronger enforcement tools, address several enforcement gaps identified in earlier literature, although this review focuses on measures that have been implemented rather than on residual weaknesses. The Special Forces for Environmental Security, a unit established under the Ministry of Interior in 2019 to enforce environmental laws and address wildlife crime, represents a further indicator of enforcement on the ground [59]. As these mechanisms mature, the foundation is established for the domain-specific progress examined in the following sections.

3.2. Biodiversity conservation and protected areas

Biodiversity and habitat protection have advanced considerably, supported by new strategies and substantial funding. Saudi Arabia established its first protected areas and a wildlife agency in the 1980s, but coverage remained limited for decades. Vision 2030 and international targets changed this trajectory; the protected areas system plan now aims to protect 30% of terrestrial and marine habitats by 2030, a goal announced under the SGI [20]. To deliver on this “30×30” commitment, the National Center for Wildlife (NCW) issued a roadmap in 2024 for designating and managing protected areas in accordance with IUCN guidance. By 2024, the Kingdom had designated 36 protected areas covering 18.1% of its land and 6.49% of its marine area, an increase from approximately 4% a decade earlier [33]. The terrestrial figure places the 30% land target within reach; attention is now shifting toward marine zones, including new coastal reserves and sanctuaries in the red sea.

The network spans a wide range of ecosystems, including deserts and wadis, wetlands, mangrove coasts, and coral-reef islands. Flagship sites such as Uruq Bani Ma'arid, a UNESCO-listed desert reserve, and the Farasan Islands Marine Sanctuary have received additional funding and staff [34]. Management relies on scientific plans, community involvement, and

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connectivity; wildlife corridors are being established to link reserves and enable species such as the Arabian oryx and Arabian leopard to move between them, both of which are being bred and reintroduced. The NCW's plan aligns site management with IUCN categories, and the Kingdom has expressed interest in IUCN Green List certification [35]. Knowledge-sharing arrangements also contribute to this effort; the IUCN has connected Saudi Arabia with other regions, such as Andalusia in Spain, on park management and governance.

Species programmes have also produced measurable results. Hunting of endangered species is prohibited, and wildlife trade is regulated under CITES. Breeding centers such as the National Wildlife Research Center in Taif have contributed to rebuilding populations of the houbara bustard, Arabian oryx, and other declining species. One secondary source reports that Saudi Arabia ranked 8th globally on the Species Habitat Index, a measure of habitat preservation [36], and ranked first on indicators for minimizing tree-cover and wetland loss [36].

Table 2. Summary of key improvements in air and water quality in Saudi Arabia.

Environmental focus	Action performed	Remarkable achievements	Future goals	References
Air quality	Establishment of monitoring networks	Saudi Arabia has established more than 240 air-quality monitoring stations across major cities and industrial zones, providing nationwide coverage of key pollutants.	Expansion of monitoring stations into additional regions, improving geographic coverage and data resolution.	[39]
	Control of pollution in industry	Concentrations of major pollutants such as PM _{2.5} , NO _x , and SO ₂ have declined due to stricter industrial regulations and improved compliance systems.	Continued reductions in industrial emissions, aligned with progressively stricter national limits by 2030.	[38, 39]
	Advanced technology-based forecasting	The country has implemented AI-enabled forecasting and high-resolution atmospheric modeling to predict dust storms and other air-quality events, enabling proactive mitigation.	Further development of next-generation forecasting models to enhance predictive accuracy and public health protection.	[38, 39]
Water quality	Improve facilities for wastewater treatment	Saudi Arabia is significantly expanding its capacity to treat and recycle wastewater, supported by more than 200 wastewater treatment plants serving agricultural, municipal, and industrial sectors.	The Kingdom aims to maximize wastewater reuse in urban areas and strengthen national water-security outcomes by advancing high-efficiency recycling technologies.	[3, 20]
	Stricter regulations on water pollution	New regulations mandate the treatment of all industrial wastewater and prohibit any discharge of untreated effluent into public water bodies, ensuring stronger environmental protection.	Sustain strict regulatory enforcement and expand monitoring mechanisms across industrial clusters and new development zones.	[40, 42, 5]

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These rankings, reported in 2021, should be interpreted with their source in mind but are consistent with the scale of recent afforestation and anti-desertification work. The SGI targets more than 600 million trees by 2030, including mangrove restoration along the coasts and reforestation of degraded dry lands [36]. The “Let's Make it Green” campaign, launched in 2020, resulted in the planting of tens of millions of trees during its early phases. Forest cover has increased modestly and degraded sites are being rehabilitated, frequently with native, drought-tolerant species. This programme is among the largest afforestation efforts undertaken in a desert setting, and has trailed techniques such as drone seeding and solar-powered nurseries.

Marine biodiversity has received similar attention. The red sea contains some of the world's northernmost coral reefs, which have demonstrated relative heat tolerance. In collaboration with the Red Sea Development Company and KAUST, the government operates coral-conservation projects and is establishing new marine protected zones. At the 2020 G20 summit, it launched a Global Coral Reef R&D Accelerator to support international reef research (SAGAR, n.d.). Closer to shore, marine wildlife, including sea turtles, dugongs, and seabirds, stands to benefit from expanded coastal protection, including the planned Red Sea mega-reserve, which would limit fishing and tourism to sustainable levels. Baseline red sea surveys have recorded species new to science, indicating how much remains undocumented [60]; a large-scale terrestrial habitat assessment conducted alongside the coastal development further extends this baseline biodiversity documentation [61]. Saudi Arabia reports regularly under the Convention on Biological Diversity and maintains a National Biodiversity Strategy aligned with Vision 2030 [2, 62].

In summary, the biodiversity record combines several strands: larger, professionally managed protected areas; species conservation and reintroduction; habitat restoration at scale; and international initiatives such as the tree-planting pledge and the coral research platform. The financial commitment is substantial, approximately SAR 50 billion across 65 environmental initiatives, including conservation. Given the Kingdom's size and the regional importance of its ecosystems, these measures have significance beyond its borders. Whether they constitute a durable model for arid-region conservation will depend on full delivery of the Protected Areas System

Plan and the “30×30” target.

3.3. Air quality management

Air-quality management has advanced through tighter regulation, improved monitoring, and targeted programmes. Clean air is a significant concern in a country with an extreme climate and rapidly growing cities, and Vision 2030 has allocated substantial resources towards this objective.

Urban air pollution in this context derives primarily from traffic, industry (including oil refining and petrochemicals), and dust storms. In response, the Kingdom has established ambient air-quality standards and industrial emission limits. The Environment Law's implementing rules specify detailed air-pollutant emission standards and vehicle-emission requirements, and the National Air Quality Management programme now coordinates monitoring through to policy response [4, 63]. Operated by the NCEC with support from the NCM, a network of nearly 240 stations provides continuous nationwide data on pollutants, including PM_{2.5}, NO_x, SO₂, and ozone [64]. Combined with satellite observations, this enables authorities to identify pollution hotspots and issue alerts. Collaboration with KAUST has also added high-resolution forecasting, utilizing the Shaheen supercomputer to anticipate pollution episodes such as sandstorms or industrial smog [64].

Government reporting indicates improved urban air quality in recent years. Concentrations of key pollutants in Riyadh and Jeddah have reportedly declined or stabilized, attributed to firmer enforcement of industrial controls and cleaner fuels, including low-sulfur diesel and the removal of lead from gasoline; an independent longitudinal analysis of PM₁₀ and PM_{2.5} trends from 2020 to 2024 supports this trajectory with measurement-based evidence [65]. Newer vehicle emission rules (Euro 5/Euro 6) and public transport investment are expected to contribute further gains. The broader shift toward efficiency and clean energy, discussed below, also contributes, as reduced oil combustion in power plants and generators results in lower SO₂ and particulate emissions. Major cities have also expanded green space; the Green Riyadh project alone aims to plant 7.5 million trees, which improves local air quality and microclimate [66]. Desert dust remains a natural challenge, but cloud-seeding and weather-modification efforts, operational since 2022, are being employed to reduce dust storms and increase rainfall. Collectively, these measures

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reflect a sustained effort on air quality consistent with Vision 2030's quality-of-life goals.

The air-quality picture depends on three interrelated factors: standards, monitoring infrastructure, and follow-up. The 240-station network and the first recorded decline in national CO₂ emissions in 2018 (examined, with verification sources, in Section 3.6) represent the clearest markers of progress. These gains are significant for public health and align with guidance from the WHO, UNEP, and IMO, including the WHO Air Quality Guidelines. The likely next step involves wider use of sensors and AI analytics in monitoring.

3.4. Water quality management

Water is a critical resource in this context, and its sustainable management has been a cornerstone of environmental compliance. The Kingdom has invested extensively in desalination for drinking water, becoming the world's largest producer of desalinated water and meeting approximately 60% of its needs through this method [67]. To protect water quality, Saudi regulations prohibit discharge of untreated industrial effluents and sewage; all major industries are required to install wastewater treatment systems and meet strict effluent standards, monitored by NCEC and the National Water Company. A notable achievement is the substantial expansion of wastewater treatment and reuse capacity: by 2021, Saudi Arabia had constructed 133 wastewater treatment plants, a 14.6% increase from the previous year, and as of 2023, the country operates approximately 200 plants treating over 5.6 million cubic meters per day [68]. Treated water is increasingly directed to agriculture, landscaping, and industrial use. It is important to distinguish the headline national target from documented progress. The Kingdom has stated an aspiration of up to 100% reuse of treated urban wastewater; however, this represents a policy goal rather than an achieved level. According to the General Authority for Statistics [69], treated wastewater contributed approximately 6.1% of total water consumption, with reuse volumes increasing by approximately 12% between 2022 and 2023 to roughly 555 million m³; a 2022 U.S.–Saudi sectoral brief cited a nearer-term target of 25% reuse by 2025 [70], while an earlier assessment reported reuse of approximately 17.3% as of 2019; a subsequent forecasting analysis projects the trajectory of treatment and reuse capacity through 2035 [71]. Progress is nonetheless evident: in Riyadh, for example, new

infrastructure at the Manfouha treatment-plant complex is directing more reclaimed water toward beneficial use rather than waste [68].

Water quality in the natural environment aquifers, lakes, and coastal waters is being safeguarded too. The government monitors groundwater quality to prevent contamination from activities like oil extraction or agriculture. Stricter rules on agricultural chemicals and improved waste disposal help protect it further. In coastal zones, Saudi Arabia actively polices against oil spills and marine pollution as a signatory to MARPOL and other treaties, with a National Contingency Plan for Marine Pollution in place [58]. Specialized regulations cover seaports and oil terminals to prevent discharges, and national industrial facilities are noted for robust environmental controls protecting marine water quality around their operations. New marine protected areas add to this too, by managing coastal development and runoff.

On the resource side, Saudi Arabia's National Water Strategy leans on conservation and sustainable use. The Kingdom has worked to reduce water demand, particularly in agriculture, which historically consumed most of it. Incentivizing modern irrigation, halting cultivation of water-intensive crops like wheat, and raising public awareness have all slowed groundwater depletion. Water distribution loss (non-revenue water) is being tackled too, through pipeline-maintenance investment, and some cities have cut water loss to under 10%, an impressive figure by international standards. Saudi Arabia also launched a Global Water Organization in 2023, headquartered in Riyadh, to foster international cooperation on water sustainability, a sign of the leadership role it wants to play on water security [67].

Water-quality management in the Kingdom, in summary, combines mandatory effluent standards and industrial pretreatment with large-scale investment in wastewater treatment, reuse, and clean energy-powered desalination, underpinned by routine monitoring from NCEC and the National Water Company. The defining challenge in this domain, in contrast to air quality, is closing the gap between treatment capacity and beneficial reuse in a water-scarce setting. The documented gains in treatment capacity and reuse volumes, rather than the aspirational 100% reuse target itself, indicate where the country's practical focus lies. These improvements benefit public health and environmental

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sustainability domestically and align with international guidelines from the WHO, UNEP, and the IMO, including UNEP's Global Environment Monitoring System standards for water quality. As Vision 2030 progresses, Saudi Arabia is expected to incorporate additional IoT sensors and AI analytics into water management and to present its large-scale, increasingly clean-energy-powered desalination as a model for other jurisdictions. Sustaining this momentum will ensure that water quality in Saudi Arabia not only meets compliance requirements but also establishes new standards for arid countries pursuing development responsibly [72].

3.5. Waste management and circular economy initiatives

Waste management constitutes a core component of environmental compliance, and this sector has been substantially modernized under a circular-economy agenda. For decades, most waste was directed to landfills with minimal recycling. Vision 2030 reversed this trend, introducing reforms and establishing targets to reduce, reuse, and recycle in accordance with circular-economy principles [42].

The 2021 Waste Management Law represented a turning point. It established a single framework for municipal, industrial, and hazardous waste; required source separation; licensed transporters and treatment facilities; and prioritized recycling and resource recovery over disposal [43]. The law also defined the role of MWAN, which oversees compliance and collaborates with the NCEC on standards for waste facilities, and introduced penalties for illegal dumping that strengthened enforcement [9].

On the institutional side, the Public Investment Fund (PIF) established the Saudi Investment Recycling Company (SIRC) to develop recycling infrastructure. SIRC has invested in new facilities across the country; one plant in Riyadh, among the largest in the region for construction and demolition waste, had recycled more than 16 million tons of concrete and debris by 2022 [44]. Specialized operators have subsequently emerged, including Tadweer for electronic waste and a large used-oil recycling plant in Yanbu serving a rapidly growing sector [70]. Private sector involvement continues to increase through public-private partnerships, with international firms contributing technology and expertise, including in waste-to-energy.

The diversion targets are substantial: by 2035–2040, the objective is to divert 85–90% of waste from landfill, with specific targets of approximately 40% recycling, 30–35% composting, and 15–20% energy recovery through incineration. Relative to a baseline in which only approximately 15% of waste was recycled in the early 2020s, these figures are ambitious, but they identify the gap the Kingdom intends to close. A review of current urban waste-management practice corroborates this baseline and the direction of reform [73]. City programmes to separate recyclables are already operational [39]. Certain waste streams have shown improvement: paper and cardboard capacity has increased, scrap metal is widely collected and processed (Al-Qaryan Group, for instance, exports recycled metal), and a plastics-recycling industry is converting waste into manufacturing pellets. Organic waste is also receiving attention, with food- and green-waste composting pilots underway in Riyadh and Jeddah through Tadweer Food Recycling Co. [54].

Innovation and public awareness are integral to this effort. The National Recycling Initiative operates public campaigns, including deposit-return schemes for beverage containers and community recycling centers, while startups receive support to generate value from waste, ranging from date palm fronds converted into building materials to waste plastic used in road asphalt. Waste-to-energy is expected to contribute to both disposal and power generation: plants that incinerate non-recyclable waste are planned to process approximately 15% of waste by 2035 [71], reducing landfill volume and counting towards renewable targets where municipal biomass is used [41].

In compliance terms, the change is evident: a previously loosely regulated sector now operates under firm rules and explicit targets. The benefit accrues in two respects: reduced local pollution, as uncontrolled dumps can contaminate soil and groundwater, and lower greenhouse-gas emissions, as landfills release methane. The circular-economy approach also connects to climate policy: diverting organic waste and recycling materials reduces emissions and the energy required to produce virgin materials. Early indications of measurable progress are evident; Riyadh reports a markedly higher diversion rate over the past five years, and pressure on overloaded landfills has begun to ease as new sorting and

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recycling capacity becomes operational [72].

3.6. Clean energy transition and climate initiatives

Climate represents one component of the environmental strategy, though it is where the Kingdom's international commitments and energy ambitions intersect most clearly. Saudi Arabia frames its climate work through the “Circular Carbon Economy”, a concept it has promoted internationally, linking mitigation to its broader compliance agenda. Work on renewables, energy efficiency, and emissions management demonstrates alignment with frameworks such as the Paris Agreement while also improving domestic environmental quality [46].

On policy, Saudi Arabia joined the Paris Agreement in 2016 with an NDC aimed at avoiding up to 130 million tonnes of CO₂-equivalent emissions a year by 2030 against a business-as-usual baseline [47]. The 2021 update raised that figure to 278 MtCO₂e a year by 2030, timed with the SGI and dependent on domestic reform and technology deployment; independent policy trackers have assessed the credibility and implied trajectory of these commitments against global benchmarks [73]. In October 2021, the Kingdom also announced an aspirational net-zero target for 2060 [49]. These commitments read as a meaningful shift for the world's largest oil exporter. The framing has been constructive throughout: the Kingdom stresses its contribution to shared goals, coordinating regional tree planting and clean-energy projects through the Middle East Green Initiative, and has taken on measures not required by international law, such as methane reduction and flaring minimization [1].

3.7. Renewable energy expansion

The clearest expression of the strategy is the shift to clean electricity. Vision 2030 targets 50% of generation from renewables, mainly solar and wind, by 2030, with the remainder from natural gas [7]. For a power sector that was almost entirely oil- and gas-fired a few years ago, this represents a substantial change and is among the more ambitious targets in the region. The National Renewable Energy Program (NREP) has delivered the first projects: the 300 MW Sakaka solar PV plant, the country's first utility-scale solar farm, operating since 2019, and the 400 MW Dumat Al-Jandal wind farm, its first utility-scale wind project [48]. Additional projects are under construction or in planning,

including the 1.5 GW Sudair Solar PV project and several further gigawatts of solar and wind capacity. Beyond emissions reduction, these plants reduce local air pollutants, as renewables produce no SO₂, NO_x, or PM. One notable plan pairs solar with desalination, which would lower the carbon footprint of water production and displace fossil-fuel use [74]. Deployment was slow initially but has accelerated since 2018: by late 2024 the Kingdom had over 2.7 GW installed, with awarded contracts expected to increase this figure substantially.

3.8. Energy efficiency and emissions management

Another pillar of the transition is improving energy efficiency across the economy. The Saudi Energy Efficiency Program (SEEP) establishes efficiency standards for appliances, buildings, and transportation and leads initiatives such as retrofitting government buildings and raising public awareness of conservation. Saudi Arabia implemented major energy price reforms in 2016 and 2018, phasing out some subsidies on gasoline, diesel, and electricity. National CO₂ emissions recorded their first decline during this period: drawing on UNFCCC-based reporting compiled in the World Bank and Climate Watch databases [75], emissions decreased from approximately 549.8 Mt in 2017 to 527.6 Mt in 2018, a reduction of approximately 4.0%. The contributing factors were varied [76], including price reform-induced demand reduction alongside slower economic activity, fuel-mix shifts in the power sector, and a milder summer, such that no single causal share can be assigned with confidence, although the IEA and BP statistical reviews provide additional verification of this trend [77, 78]. The price reform component specifically was modelled separately [51]. This was a significant development, as Saudi Arabia had historically maintained one of the highest per-capita energy consumption rates globally. By framing efficiency as both an economic and environmental benefit, the Kingdom reduced domestic oil consumption for power generation, thereby freeing crude oil for export while reducing pollution, and encouraging industries to adopt more efficient technologies. Compliance in buildings is governed by the Saudi Energy Conservation Code (SBC 602) under the Saudi Building Code [78], which specifies envelope, HVAC, lighting, and ventilation requirements and includes an Administration and Enforcement chapter integrated into the municipal permitting process. In transport, Saudi Arabia

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applies a national Corporate Average Fuel Economy standard to all incoming light-duty vehicles (SASO 2864). The Saudi Standards, Metrology and Quality Organization (SASO) and the Saudi Energy Efficiency Center (SEEC) publish annual OEM-level compliance and credit balances, with target ranges tightening from 15.7–21.0 km/L in 2024 to 18.5–24.8 km/L in 2028. Early indications suggest efficiency gains in the incoming fleet, including an increase in hybrid penetration compared with 2016–2019 baselines. These instruments contribute to the Kingdom's NDC implementation and are tracked in Saudi Arabia's Biennial Transparency Report. Not all changes in national energy intensity can be attributed solely to these policies; however, intensity has generally improved in recent years, consistent with the broader efficiency initiatives [79-81].

3.9. Carbon Capture, Utilization, and Storage (CCUS) and hydrogen

Saudi Arabia's climate initiative includes pioneering projects in carbon management. The Circular Carbon Economy (CCE) concept, promoted by Saudi Arabia and endorsed during its G20 presidency, frames reducing, reusing, recycling, and removing carbon emissions as a unified approach [51]. In practice, alongside reducing emissions through renewables and efficiency, Saudi Arabia is investing in carbon capture and storage (CCS) and exploring low-carbon hydrogen production. One operational example is the CCS project at the Uthmaniyah gas plant, which captures approximately 0.8 MtCO₂ annually for use in enhanced oil recovery, with plans to substantially scale CCS in the power and industrial sectors. Regarding hydrogen, Saudi Arabia is constructing one of the world's largest green hydrogen plants in NEOM, powered by 4 GW of renewable energy, to produce green ammonia for export [52], while concurrently developing “blue” hydrogen from natural gas with CCS. These projects reflect a broader strategy of maintaining energy leadership in a low-carbon world through innovation in clean fuels. Rather than treating CCS or hydrogen as contentious, Saudi policy presents them as new industries that will contribute to emissions targets and drive economic diversification, representing opportunity rather than obligation. According to the developer, the NEOM green hydrogen plant was approximately 80–90% complete as of early 2025–2026, with its 4 GW of wind and solar generation scheduled for

completion by mid-2026 [82, 83]; electrolyzer commissioning and initial green-ammonia output are scheduled for 2027 rather than 2026. Independent reporting has also noted offtake-demand uncertainty, with only one international buyer committed to date [84]. The project's stated objective of avoiding on the order of 5 Mt of CO₂ annually should therefore be understood as conditional on full operation and secured demand; domestically, the expertise gained from such projects is expected to strengthen environmental compliance in industrial processes [53].

Saudi climate policy, previously viewed with scepticism internationally, now relies on international cooperation and clearer reporting. The Kingdom participates in UNFCCC conferences and joined the Global Methane Pledge in 2022 [85], and has begun publishing annual sustainability and environmental indicators, improving available data on emissions and mitigation. The overall direction is toward narrowing the gap between targets and delivery: renewable deployment, initially slow, is accelerating; efficiency measures have produced measurable savings; and pilot projects in carbon capture and renewables integration are underway. Saudi analysts note that rendering the CCE fully operational will require robust carbon accounting and additional support for early-stage technologies [86], while also observing that these efforts “signal a stronger level of engagement on climate policy” by the Kingdom.

The international framework for quantifying and reporting these figures has itself recently evolved. The ISO 14064 series, which underlies most third-party-verified national and corporate GHG inventories, was extended in 2025 with a new implementation guidance document, ISO/TS 14064-4:2025, clarifying boundary-setting and quantification methods for organizational inventories [87]. More significantly, in September 2025, ISO and the GHG Protocol, the framework referenced in Saudi Arabia's own NDC and Biennial Transparency Report methodology, announced a strategic partnership to harmonize the ISO 1406X series with the GHG Protocol's Corporate, Scope 2, and Scope 3 Standards into a single co-branded set of standards, with a joint product-carbon-footprint standard also under development through a dedicated Joint Working Group [88]. For Saudi Arabia, this convergence bears directly on the carbon-accounting gap noted above: as the Kingdom's national inventory, Circular

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Carbon Economy accounting, and CCUS/hydrogen offset claims increasingly need to satisfy international verifiers, financiers, and disclosure regimes concurrently, alignment with this emerging unified standard would reduce the risk of methodological inconsistency between domestic reporting and the frameworks used by trading partners and financiers. As this harmonization process only commenced in 2025 and remained under active development at the time of writing, its practical implications for Saudi Arabia's reporting practice should be regarded as an emerging rather than settled area, warranting monitoring in future updates of this review.

On balance, the climate and clean-energy work demonstrates alignment with international expectations alongside domestic co-benefits. It encompasses high-level pledges, such as the 2060 net-zero goal, and concrete developments on the ground: solar and wind farms are now a visible component of the landscape, the energy intensity of GDP is declining, and new industries, including solar-panel assembly, wind-turbine components, and hydrogen, are reducing reliance on oil. The framing of climate policy has shifted toward one of leadership and opportunity. Under the SGI, which lists more than 85 initiatives and over SAR 700 billion of stated investment in the green economy, as detailed in the initiative's most recent annual reporting [20, 89], the Kingdom emphasizes its contribution to shared solutions. For other Gulf States, it provides a working example: an oil producer can invest in a cleaner energy base, fulfill its international commitments, and incorporate climate goals into national development plans.

3.10. Future opportunities and strategic directions

Saudi Arabia's environmental compliance and excellence journey, while marked by substantial progress to date, remains a dynamic and ongoing process. As the Kingdom consolidates its achievements, it is also identifying opportunities to build upon them. Rather than treating remaining gaps as problems, Saudi Arabia tends to frame them as strategic opportunities for further improvement, innovation, and international collaboration. The priority directions presented below are derived from gaps and recommendations identified in the included literature, particularly analyses of renewable-energy investment under Vision 2030 [7, 8], governance audit mechanisms and ESG-related emissions performance [32], and public-sector innovation and technology adoption [73], together with further policy syntheses [90, 91]. For readability,

and consistent with the format used in several of these policy syntheses, these directions are presented as a bulleted list rather than continuous prose:

- **Enhancing Renewable Energy Deployment:** As the renewables sector matures, opportunities exist to exceed current targets and incorporate emerging technologies. The Kingdom's land and solar resources support next-generation panels, including local manufacturing, and battery storage, which together could increase the clean-energy share further after 2030. Linking renewables to desalination and to industrial supply, such as solar process heat for refineries, would reduce emissions further and demonstrate sustainable industrial practice at scale.
- **Strengthening Environmental Monitoring and Data Management:** Digital tools and analytics can improve the efficiency of compliance monitoring. The existing progression toward smart monitoring could be extended through IoT sensors on industrial sites, satellite imagery for real-time detection of land and marine pollution, and predictive analytics for environmental incidents. The NCEC–KAUST partnership provides a useful template; comparable arrangements could encompass water-quality modelling or biodiversity monitoring, utilizing drones and remote sensing to track wildlife. Publishing the resulting data openly would help maintain public trust.
- **Public Engagement and Education:** Vision 2030 also emphasizes the role of the public. Citizens and residents can be engaged through community recycling, citizen science in biodiversity (for instance, reporting wildlife sightings), and conservation-focused school curricula. Programmes such as King Salman's Sustainable Development initiative have already contributed to localizing sustainable practice. Cultivating a culture in which environmental responsibility is routine would reduce the burden on regulators and encourage compliance beyond what enforcement alone achieves, thereby helping sustain these gains.
- **International Leadership and Cooperation:** Opportunities also exist to share expertise and learn from other jurisdictions. The Kingdom can expand its participation in international forums, hosting events such as the Middle East Green Initiative Summit and contributing to global climate and biodiversity funds. The Riyadh-based Global Water Organization represents one such step; a regional center on

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desertification could constitute another. Through South–South cooperation, Saudi Arabia could assist other developing countries in adopting approaches that have proven effective locally, such as water reuse or afforestation in arid land.

- **Economic Diversification through Green Innovation:** Green industries represent an economic opportunity in their own right. Clean technology, including solar manufacturing, electric vehicles, and green hydrogen, together with environmental services such as recycling, consulting, and protected-area ecotourism, all contribute to Vision 2030's diversification goal. Sustained investment in these areas positions the Kingdom to attract capital and expertise, create employment, and link economic development with environmental protection rather than treating them as competing objectives.

A consistent pattern is evident across these priorities: where an indicator lags, the typical response is a defined target supported by resources, as demonstrated by the waste-diversion and wastewater-reuse goals. The institutional framework now possesses the capacity to address emerging issues, including new pollutants and climate-adaptation needs such as cooling and urban greening for extreme heat. As Vision 2030 progresses into its next phase, environmental objectives are increasingly incorporated into the plans of other sectors rather than treated separately.

In summary, this section's trajectory reflects a progression from building basic capacity to operating a maturing system. The opportunities identified above would strengthen the Kingdom's standing in environmental governance. The broader implication is that environmental protection has proved compatible with, and at times supportive of, the goals of economic and social development.

3.11. Certainty of evidence

Certainty in the body of evidence underpinning each of the six thematic domains was rated using a GRADE-informed narrative approach, considering study design, methodological quality, consistency across sources, directness, precision, and risk of publication bias; the full rating matrix, including the number of contributing studies and the predominant study designs per domain, is reported in Supplementary Table S4. Because the review synthesizes descriptive policy evidence rather than pooled effect estimates, ratings are assigned at the

domain level rather than at the level of individual outcomes.

Certainty was rated Moderate for governance reforms and compliance institutions (18 contributing sources), reflecting convergent description across multiple peer-reviewed legal analyses and official documents, tempered by substantial reliance on government and agency self-reporting and limited independent verification of enforcement outcomes.

Certainty was rated Low to Moderate for biodiversity and protected-area coverage (11 sources), air quality (9 sources), and water quality and wastewater reuse (10 sources). In each of these domains, headline figures, including protected-area extent, pollutant-concentration trends, and treatment-plant counts, recur across multiple sources but originate from a limited number of underlying government baselines, and independent, peer-reviewed measurement or effectiveness studies remain comparatively scarce.

For waste management and circular-economy outcomes (9 sources), certainty was rated low, given that the 2035–2040 diversion targets represent forward-looking projections and current baseline recycling rates are reported inconsistently across sources, with few longitudinal datasets available.

For clean energy and climate (21 sources), certainty ratings differed by outcome type: Low for projected outcomes, as the 2030 renewable-electricity target and the 2060 net-zero pathway both rest on modelled projections, and Moderate for current installed capacity and code-based efficiency standards, which can be verified directly against published capacity figures and compliance filings.

A consistent pattern is evident across domains: certainty is higher where claims can be verified against a discrete, verifiable record, such as installed capacity, plant counts, or legal instruments, and lower where claims represent projections or depend primarily on a single reporting source. This distinction motivates the priority directions for independent monitoring and verification set out in Section 3.10.

3.12. Significance of this review and the imperative for rigorous net-zero adherence

This review is significant because Saudi Arabia's environmental transformation is proceeding at a pace and scale that exceeds independent scholarly synthesis: most of the underlying evidence remains distributed across government

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reports, ministerial communications, and a rapidly growing but fragmented peer-reviewed literature. By consolidating this evidence within a single PRISMA-compliant framework, this review offers policymakers, investors, and researchers a structured, source-checked account of what has been achieved, what remains aspirational, and where the evidence base requires strengthening. This is of practical value not only for Saudi Arabia but also for other hydrocarbon-exporting, arid-climate jurisdictions in the Gulf and beyond that face similar dual challenges of economic diversification and environmental stewardship [24, 25]. A transparent account of what is known, and the degree of confidence with which it is known, constitutes a precondition for credible policy design and for meaningful comparison across countries pursuing similar reform pathways.

Among the outcomes reviewed, the Kingdom's net-zero-by-2060 commitment carries disproportionate weight, both symbolically and practically. Symbolically, it repositions a historically hydrocarbon-centric economy as a stated participant in the global climate regime, consistent with its accession to the Paris Agreement [47]. Practically, it constitutes the organizing target against which the renewable-electricity build-out, the Circular Carbon Economy approach, CCUS deployment, and the hydrogen pipeline are sequenced [49, 79]. Strong adherence to this target is important for several converging reasons. First, the least-cost modelling reviewed here indicates that early, sustained investment in renewables and efficiency is markedly less costly than a delayed transition reliant on carbon capture at scale later [49]; consequently, slippage now increases the cumulative cost of later action. Second, the domestic co-benefits are substantial and immediate: displacing liquid fuel from power generation frees crude oil for export, reduces urban air pollution and its associated health burden (Section 3.3), and lowers the water intensity of the energy sector, an important consideration given the water-quality and scarcity pressures documented in Section 3.4. Third, credibility with international partners, financiers, and rating agencies increasingly depends on demonstrated delivery rather than announced ambition; as green and sustainability-linked finance mechanisms mature, verified emissions performance is becoming a condition of access to capital, rather than solely a reputational consideration [92, 93]. Fourth, a firm and monitored trajectory

reduces the risk that current infrastructure investment becomes stranded under tightening global carbon constraints, thereby protecting the value of the diversification projects that Vision 2030 is designed to deliver.

At the same time, the certainty ratings applied throughout this review constitute a deliberate caution against treating the 2060 pathway as already secured. As Section 4 (Limitations) notes, the evidence for long-horizon targets, including the 2060 net-zero pathway and the 2030 renewable-electricity target, is presently rated low to moderate, resting more on modelled projections and government communications than on independent, longitudinal outcome verification [49, 50, 79]. Closing this evidence gap is not a peripheral academic concern; it constitutes a precondition for adherence itself, as targets that are not independently measured cannot be reliably corrected should delivery deviate from course. The priority directions identified in Section 3.10, particularly independent monitoring and verification programmes and the publication of disaggregated outcome data, should therefore be understood as directly supporting the net-zero commitment, rather than constituting a separate governance improvement. Ultimately, the value of this review lies as much in clarifying what remains unknown as in documenting what has been achieved, and the value of strong net-zero adherence lies as much in the rigor of its verification as in the ambition of its target.

4. Limitations

4.1. Limitations of the evidence base

Several characteristics of the included evidence limit the strength of the inferences that can be drawn. A substantial share of the quantitative claims, including reductions in PM_{2.5}, NO_x, and SO₂ concentrations; wastewater reuse percentages; and CO₂ emission trends, are derived from government reports and ministry communications rather than independent, peer-reviewed measurement studies; where both were available, these were triangulated, but for several outcomes only one source type was identified. Projected outcomes, including the 2030 renewable target, the 2060 net-zero pathway, and the 2035–2040 waste-diversion targets, are aspirational rather than achieved, and certainty regarding their realization is low. English-language eligibility may also have excluded Arabic-language regulatory and grey literature; future updates should incorporate Arabic-language searches.

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Longitudinal evaluations that track a specific reform from baseline to post-implementation are rare within this evidence base; most studies are descriptive cross-sections. Additionally, because the review spans 2000–2025, several cited studies, particularly in the air-quality and marine/biodiversity domains, predate the 2016 energy-price reforms and the 2020/21 Environment Law. This earlier work should be interpreted as documenting baseline conditions rather than the impact of recent governance reforms; post-Vision 2030 outcomes have not been attributed to this earlier evidence.

5. Conclusion

Over a relatively short period, Saudi Arabia has reshaped its environmental governance and emerged as one of the more active reformers in the region. New agencies such as the NCEC, revised laws with clear mandates for pollution control and enforcement, and alignment with ISO standards, EIA protocols, and international conventions now bring the Vision 2030 framework in line with, and in places ahead of, international practice. Much of the supporting evidence, however, comes from government sources, so the picture is one of substantial, documented activity rather than fully independent verification.

Concrete progress is visible across domains: larger protected areas and species recovery in biodiversity; nationwide monitoring and early signs of pollutant reduction in air quality; expanded wastewater reuse and desalination capacity in water; higher recycling and less landfill in waste; and renewable deployment, efficiency measures, and carbon-capture and hydrogen projects in energy and climate. The Kingdom has also framed this work in constructive terms with, tree planting at scale, green jobs, regional initiatives, and knowledge sharing, which has earned recognition on several international indicators, though that data should still be read with its government sources in mind.

These efforts are closely tied to the wider development agenda: embedding environmental targets across Vision 2030's infrastructure, economic, and social programmes has improved cross-ministerial coordination, opened funding channels, and drawn in private sector and community participation, mapping onto several UN Sustainable Development Goals. The experience suggests that, given political will, a clear plan, and adequate resources,

environmental compliance can improve quickly when top-down reform is paired with bottom-up public engagement and supported by measurement and accountability. The central caveat carried throughout this review remains: durable conclusions will require more independent, long-term outcome data alongside the official record. If this momentum is sustained, the Kingdom is well placed to deliver on its sustainability goals. Its experience under Vision 2030 suggests that economic growth and environmental protection need not be in tension and can, with the right institutions, reinforce one another.

Author contributions

The author conceived and designed the study, performed the data analysis, and wrote the main manuscript. All aspects of the work were carried out solely by the author. The intellectual content and authorship of this work are entirely the author's. One additional individual contributed only to dual-screening of a 20% random sample of records and to verification of data extraction for that sample; this contribution does not meet ICMJE authorship criteria, and the individual is recognized in the Acknowledgements rather than as a co-author.

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“Generative AI technological tool was used in drafting the structural elements of the Methods section, PRISMA-aligned phrasing, structuring of the PECO frame, and the certainty-rating language from author-prepared notes. Formulation of the manuscript’s scientific conclusions.”

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Data availability

All study data and materials are published in the manuscript.

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