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Review Paper

From COP Commitments to Environmental Ethics: A Comprehensive Review of Decarbonization Pathways for the UAE Built Environment

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ABSTRACT

The decarbonization of the built environment in the United Arab Emirates (UAE) has moved from a narrow energy-efficiency agenda to a broader socio-technical transformation challenge that includes operational carbon, embodied carbon, water stress, climate adaptation, urban governance, and environmental ethics. Building on the legacy contribution of Locke et al. (2023) and confined strictly to the user-supplied evidence base, this review synthesizes the attached extraction set to update the state of knowledge on UAE-relevant decarbonization strategies after COP26 and COP27. The review adopts a structured narrative synthesis of the supplied literature and organizes the evidence into five connected domains: climate governance and ethical justification; passive and envelope-led operational carbon reduction; life-cycle and circular material strategies; water-energy-material nexus innovations; and social, behavioral, and justice-oriented dimensions of climate-resilient urbanism. Across the literature, the strongest message is that no single technology can deliver deep decarbonization in hot-arid urban contexts. Instead, durable progress depends on combining passive cooling, stricter and harmonized codes, urban-scale energy modeling, renewable integration, life-cycle thinking, atmospheric and desalination-linked water strategies, and occupant-centered governance. The review argues that environmental ethics should become an explicit design principle rather than an implicit background concern, because decisions on comfort, water, material intensity, digitalization, and adaptive capacity are inherently distributive and intergenerational. A UAE-specific integrative framework is proposed to connect policy ambition, urban form, building design, infrastructure, and community action. The article concludes by outlining a next-generation research agenda for net-zero and climate-resilient urban development in the UAE and similar Gulf settings.

Keywords: UAE built environment; decarbonization; environmental ethics; passive design; embodied carbon; water-energy-material nexus; climate resilience

1. INTRODUCTION

The UAE built environment is now central to climate mitigation because buildings and urbanization concentrate energy demand, materials, water use, and exposure to future heat. The anchor article by Locke et al. (2023) framed this challenge through COP26 and COP27 recommendations and the practical integration of energy, water, and waste strategies. The broader extraction supplied for this review confirms that this framing remains valid, but it also shows that the debate has widened. Decarbonization is no longer discussed only as a problem of efficient equipment or better individual buildings. It is increasingly treated as a socio-technical transformation involving urban form, passive design, life-cycle impacts, digitalization, climate vulnerability, and public legitimacy (Locke et al., 2023; Wang et al., 2022; Dwivedi et al., 2022; Ji et al., 2022).

For the UAE, the shift matters because cooling demand sits at the center of the carbon problem. Earlier reviews already showed that rapid urban growth in the Gulf produced some of the most resource-intensive building systems in the world and that the UAE's development trajectory became deeply tied to cooling-intensive construction, high electricity use, and growing material throughput (Asif, 2016; Radhi, 2010; Friess & Rakhshan, 2017). More recent studies add two critical refinements. First, future warming changes the relative value of passive design measures, meaning that envelope design, shading, urban geometry, and glazing cannot be optimized only for current conditions (Pajek et al., 2022; Hong et al., 2022; Salameh & Touqan, 2022). Second, social and ethical questions are no longer peripheral. Climate exposure, access to comfort, the burden of cooling dependence, and uneven adaptive capacity all shape whether decarbonization is technically effective and politically durable (Mann, 2009; Ehsan et al., 2022; Andersson-Sköld et al., 2015).

This review therefore advances a single core claim: the most credible pathway for the UAE built environment is nexus-based, climate-adaptive, and ethically explicit. That means decarbonization must be pursued simultaneously across operational energy, embodied carbon, water systems, resource circularity, urban design, and social adaptation rather than through isolated "green building" upgrades. The aim of the article is not to add web-sourced evidence beyond the user-supplied files, but to reorganize the supplied literature into a sharper analytical model that can support publication-quality discussion. The review asks what kinds of pathways the evidence actually supports, which strategies appear strongest in UAE and Gulf conditions, and how environmental ethics can be translated from abstract principle into design, code, procurement, and governance criteria (Kuh, 2017; Khasreen et al., 2009; Zhou et al., 2020; Abuzaid et al., 2022).

2. Review scope, evidence base, and synthesis logic

This article is deliberately bounded by the materials provided by the user. It is built from the anchor abstract of Locke et al. (2023) and the accompanying extraction file, which includes journal articles, reviews, chapters, and a limited number of policy or commentary items. No new references were introduced from the web. The resulting article is therefore not a new systematic search, but a structured narrative review constrained to the supplied evidence base. This boundary is methodologically important because some entries in the extraction are bibliographically incomplete; consequently, the synthesis emphasizes the better-specified and more analytically useful records while preserving fidelity to the source set (Locke et al., 2023).

Narrative synthesis is appropriate because the dataset is heterogeneous in method, scale, and purpose. It spans life-cycle assessment reviews, stock-level energy modeling, building code analysis, passive design studies, social perception work, climate law overviews, climate risk assessments, and water-harvesting reviews. A more rigid quantitative synthesis would obscure rather than clarify the strategic patterns in such a dataset. The goal here is instead to identify recurring design logics and policy implications that can inform the UAE built environment as a coupled system rather than a set of disconnected technical subfields (Rashid et al., 2019; Wang et al., 2022; Khasreen et al., 2009).

Five thematic streams organize the discussion: climate governance and environmental ethics; operational carbon and passive design; embodied carbon and circularity; the water-energy-material nexus; and social legitimacy, vulnerability, and justice. These streams are analytically distinct but practically interdependent. The synthesis gives particular weight to the 2020–2025 portion of the extraction where newer studies refine the post-COP agenda, future-climate design, stock modeling, circular homes, BIPV performance, and air-water harvesting. At the same time, older foundational works remain central where they define enduring concepts such as life-cycle assessment, envelope performance, dangerous anthropogenic interference, and the mitigation role of buildings (Balaras et al., 2000; Sadineni et al., 2011; Mann, 2009; Lucon et al., 2014).

Environmental ethics is used here as an interpretive lens rather than an ornamental theme. It asks who benefits from current forms of cooling-intensive development, who bears the burdens of emissions and resource dependence, and whether present design choices preserve room for future adaptation. That lens is useful because the supplied literature repeatedly shows that technical optimization alone is insufficient. Passive design, life-cycle accounting, urban greenery, renewable systems, digitalization, and community engagement all carry distributive consequences. A review that makes those consequences explicit is better able to evaluate not only what reduces emissions, but what does so in robust and socially legitimate ways (Kuh, 2017; Dwivedi et al., 2022; Pörtner et al., 2022).

The evidence architecture used throughout the review is summarized in Table 1.

Table 1. Evidence architecture of the supplied literature and its relevance to the UAE built environment

Thematic stream	Dominant scope and methods	Main insight contributed by the literature	UAE/GCC relevance	Principal gap for next-stage research	Ref.
Climate governance and environmental ethics	COP analyses, legal overviews, climate framing, editorial and policy reflections	Decarbonization depends on institutional commitments, implementation capacity, and explicit attention to fairness, responsibility, and intergenerational risk	High, because UAE pathways are shaped by COP-linked agendas, national plans, and international legitimacy pressures	Limited translation from diplomatic commitments to building-scale metrics and ethical design criteria	Wang et al. (2022); Kuh (2017); Owens and McAdam (2021)
Operational carbon and passive design	Reviews, simulations, regression studies, stock modeling, building code analysis	Envelope quality, shading, glazing, orientation, ventilation, and urban morphology are decisive in cooling-dominated contexts	Very high, because the UAE remains cooling intensive and code heterogeneity persists	Need for future-climate-responsive design standards and urban-scale performance baselines	Friess and Rakhshan (2017); Pajek et al. (2022); Ji et al. (2022)
Embodied carbon, life-cycle thinking, and circularity	LCA reviews, structural comparisons, comprehensive life-cycle scenarios, circular economy approaches	Operational gains can be offset if embodied impacts, end-of-life effects, and circular material flows are ignored	High, due to material-intensive growth and the importance of early-stage structural choices	Sparse UAE-specific embodied carbon datasets and limited coupling between LCA and design regulation	Khasreen et al. (2009); López-Mesa et al. (2009); Li et al. (2020)
Water-energy-material nexus	Reviews of atmospheric	Water security and decarbonization	Very high, given water	Need integrated	Zhou et al. (2020);

	water harvesting, desalination updates, solar steam generation, resource optimization	are mutually dependent in arid cities; infrastructure choices carry energy and carbon implications	scarcity and desalination dependence in the Gulf	urban scenarios linking buildings, desalination, distributed water capture, and renewable electricity	Thavalengal et al. (2023); Irshad et al. (2021)
Social perception, adaptation, and justice	Surveys, vulnerability assessments, integrated adaptation methods, community engagement	Effective decarbonization requires public legitimacy, occupant uptake, and adaptation measures that do not worsen inequality	High, especially for residential transitions and heat-stress management	Need UAE-specific studies connecting social acceptance with retrofit, pricing, and climate risk exposure	Abuzaid et al. (2022); Ehsan et al. (2022); Andersson-Sköld et al. (2015)

Table 1 shows that the strongest value of the dataset lies in integration. The literature does not support treating ethics, codes, materials, water, building envelopes, and user behavior as separate policy compartments. Instead, it points toward decarbonization as a transition system in which weaknesses in one layer can undermine gains in another.

3. From climate governance to environmental ethics in the built environment

A notable shift in the supplied literature is the repositioning of climate action from a narrow environmental-management issue to a combined governance, development, and ethical challenge. COP26 is presented as a milestone because it finalized major elements of the Paris Rulebook and intensified attention to implementation, finance, collaboration, and sectoral responsibility, even as it exposed a continuing gap between ambition and delivery (Wang et al., 2022; Owens & McAdam, 2021). COP27 moved the discussion further toward implementation and the built environment as a site where climate action must become materially real rather than rhetorically aspirational (Alayza, 2022; COP27: Built Environment Accelerates Climate Action, 2022; Locke et al., 2023). For the UAE, this is significant because buildings, districts, and infrastructure are the points at which global commitments are translated into codes, procurement, and everyday comfort regimes. Kuh's (2017) overview of climate mitigation law is useful because it shows that implementation does not hinge on a single instrument. It depends on the interaction of international commitments, domestic regulation, standards, incentives, and accountability. Read alongside Gulf-focused studies, this suggests that UAE decarbonization will depend less on whether targets exist in principle and more on whether measurement systems, code thresholds, and enforcement practices are aligned with real design decisions (Kuh, 2017; Rodriguez-Ubinas et al., 2020; Asif, 2016). That reading shifts attention from symbolic commitment to operational governance. It also explains why post-occupancy transparency, whole-life accounting, and code harmonization are increasingly important in a top-tier decarbonization agenda.

Environmental ethics sharpens this governance perspective by asking what is at stake when climate action is delayed or partial. Mann (2009) framed the issue through the idea of dangerous anthropogenic interference, foregrounding thresholds, risk, and responsibility. Later climate-risk literature shows that impacts, adaptation, and vulnerability are already entangled and that the attribution of extreme weather to climate change has become increasingly credible

(Clarke et al., 2022; Pörtner et al., 2022). For built environment research, the implication is clear: decisions about urban form, cooling dependence, material intensity, water systems, and adaptive design are not neutral technical choices. They influence who is exposed to heat, who pays for comfort, and how much risk is transferred into the future.

This matters acutely in hot-arid urbanism. If thermal comfort is delivered primarily through high-energy mechanical cooling, then access to comfort becomes a distributive issue tied to buildings, tariffs, and urban design rather than a neutral service outcome (Radhi, 2010; Friess & Rakhshan, 2017; Abuzaid et al., 2022). Water intensifies the point. In desalination-dependent environments, water supply carries energy and carbon costs, while uneven adaptive capacity can make scarcity more burdensome for some groups than others (Zhou et al., 2020; Thavalengal et al., 2023; Davids, 2022). Ethical analysis therefore widens the object of decarbonization from "efficient buildings" to responsible urban metabolism.

The digitalization literature provides a useful warning. Dwivedi et al. (2022) argue that digital technologies can be part of both the climate solution and the climate problem. For the built environment, this means smart controls, IoT monitoring, and urban dashboards should not automatically be treated as sustainability gains. They can improve resource coordination, but they can also add material demand, e-waste, energy use, and governance complexity if deployed without a responsible framework (Dwivedi et al., 2022; Kaklauskas & Gudauskas, 2016; Climate Action, 2021). The same concern appears in the adaptation literature, which warns against maladaptation and favors multifunctional, integrated measures over siloed solutions (Andersson-Sköld et al., 2015).

Taken together, the governance and ethics literature supports a practical conclusion: environmental ethics should be operationalized in the UAE built environment through measurable criteria. These include whole-life carbon accounting, future-climate-responsive performance standards, transparent operational data, and decision frameworks that explicitly surface trade-offs among carbon, water, comfort, and resilience. In this review, ethics is therefore used as a test of seriousness. It asks whether a decarbonization pathway reduces foreseeable harm, avoids burden shifting, and expands adaptive capacity rather than merely improving selected performance indicators (Kuh, 2017; Locke et al., 2023; Pörtner et al., 2022).

4. Updating the UAE and GCC decarbonization context

The original review by Locke et al. (2023) positioned the UAE as an active participant in COP-linked decarbonization and used the G+2 SEE Institute building to illustrate the integration of energy, water, and waste strategies. The wider evidence base confirms the relevance of that framing but situates it within a larger structural problem. The UAE cannot be understood simply as a place that needs more efficient buildings. It is a cooling-dominated, rapidly urbanizing, infrastructure-heavy system in which urban form, material intensity, and institutional heterogeneity jointly shape emissions trajectories (Locke et al., 2023; Asif, 2016; Rodriguez-Ubinas et al., 2020).

Asif (2016) remains foundational because it places the UAE within a GCC growth model characterized by intense construction activity, high per-capita energy use, and substantial environmental pressure. Radhi's (2010) earlier warning about global warming and the UAE built environment appears prescient in this light: the region's decarbonization challenge was visible well before net-zero language became widespread. What is new in the current literature is not recognition of the problem, but the development of more precise leverage points for response.

Friess and Rakhshan (2017) provide one of the clearest UAE-specific syntheses of those leverage points. Their review shows that delayed code development, subsidized electricity, and rapid growth produced a built environment in which the quantity of construction often outpaced energy quality. Their reported performance ranges are strategically important: insulation can exceed 20% savings in residential settings, glazing and orientation can cut demand sharply in highly glazed offices, and mixed-mode ventilation can produce very large reductions in appropriate typologies. These findings confirm that passive and envelope measures remain among the highest-return interventions in the UAE context (Friess & Rakhshan, 2017).

Rodriguez-Ubinas et al. (2020) reinforce this conclusion at the governance level. Their comparative work shows that cooling dominates electricity demand and peak load in the UAE and that code thresholds still vary across Emirates. This variation matters because it creates uneven market expectations and slows the normalization of high-performance design. The same literature also indicates that the UAE debate is moving beyond energy performance alone. Abuzaid et al. (2022) show that sustainability perceptions differ across demographic groups, implying that decarbonization policies such as retrofits, tariff shifts, or low-carbon housing standards will not be socially neutral. Salameh and Touqan (2022) add another important correction: traditional urban fabrics in the UAE perform thermally better than many modern districts, suggesting that vernacular principles remain valuable resources for contemporary climate-responsive design.

This broader diagnosis also helps explain why the UAE is strategically important beyond its own borders. It is an early test case for whether high-growth, high-cooling, water-constrained urban systems can decouple development from intensifying resource use without sacrificing livability. Because the UAE combines ambitious climate signaling with a continuing pipeline of urban expansion, it offers a setting in which regulatory design, passive performance, and whole-life accounting can either converge into a new model of Gulf urbanism or remain compartmentalized into exemplary but isolated projects. That is precisely why a systems reading of the literature matters: it reveals where policy ambition still needs institutional translation and where design knowledge is already sufficient to justify stronger baseline expectations (Asif, 2016; Friess & Rakhshan, 2017; Locke et al., 2023).

The updated UAE context is therefore best described as a coupled challenge of operational emissions, embodied impacts, thermal risk, water dependence, fragmented regulation, and differentiated social adaptation. Flagship developments and pilot projects may still matter, but the post-COP literature makes clear that demonstration without diffusion is inadequate. The next phase of UAE decarbonization will be credible only if passive-first design, whole-life thinking, integrated resource systems, and social legitimacy move from exemplary projects into mainstream planning and building practice (World Green Building Council, 2022; Rogmans, 2025; Locke et al., 2023).

5. Operational carbon reduction: passive design, envelopes, urban form, and performance governance

Operational carbon remains the most developed domain in the supplied literature, but the newer studies encourage a more strategic interpretation of it. The older framing often treated energy efficiency as a sequence of component upgrades. The current literature instead emphasizes hierarchy: in cooling-dominated climates, carbon performance is shaped first by form, shading, glazing, insulation, façade configuration, and urban context, and only then by the efficiency of active systems. This shift is crucial for the UAE because cooling demand is structurally embedded in the design of buildings and districts long before HVAC equipment is specified (Sadineni et al., 2011; Friess & Rakhshan, 2017; Pajek et al., 2022).

Sadineni et al. (2011) remain central because they synthesize the building envelope as the first line of energy reduction. More recent work extends that insight into a future-climate frame. Pajek et al. (2022) show that the relevance of passive measures changes under warming scenarios rather than disappearing. In cooling-relevant contexts, shading, glazing ratios, and façade configuration become even more significant, which means that design standards should be tested not only against current weather files but also against hotter projected futures. For the UAE, this is not a subtle point. If buildings are optimized only for present conditions, today's efficiency gains may become tomorrow's maladaptations.

The UAE-specific evidence strongly supports a passive-first agenda. Friess and Rakhshan (2017) identify orientation, insulation, glare control, glazing selection, and ventilation strategy as major determinants of performance. These are not minor design refinements. They alter the underlying cooling burden and therefore the operating carbon profile of the building across its full service life. The same logic applies at the district scale. Ji et al. (2022) show that urban surroundings, shading patterns, and stock characteristics materially influence energy use intensity, implying that building-only models can underestimate the way urban morphology produces demand. In fast-growing Gulf cities, operational carbon policy should therefore be built on both archetype-level and urban-scale evidence (Ji et al., 2022; Yang & Choi, 2015).

Multi-objective and climate-adaptive design studies refine the same message. Ascione et al. (2015) demonstrate that envelopes should be optimized for comfort as well as energy, avoiding the false dichotomy between efficiency and inhabitability. Hong et al. (2022) show that the relative importance of plan ratio, core location, atrium effects, and glazing shifts by climate, while Salameh and Touqan (2022) demonstrate that traditional urban forms in the UAE can outperform many modern districts thermally. The implication is that modernization should not be equated with glass-heavy, fully conditioned urbanism. Many durable low-carbon principles are historically tested and remain relevant when reinterpreted with contemporary materials and codes (Fernandes et al., 2014; Salameh & Touqan, 2022).

The literature on BIPV and active façades adds useful nuance rather than overturning this hierarchy. Studies of ventilated claddings, PV façades, and low-cost passive cooling for BIPV all suggest that renewable integration performs best when it is designed in relation to thermal dynamics, cavity airflow, maintenance, and envelope behavior (Rahiminejad et al., 2022; Benzarti et al., 2022; Rodríguez-Gallegos et al., 2018). Renewable systems can therefore deepen operational decarbonization, but they do not substitute for poor passive design. The code literature makes the governance implication explicit: fragmented or modest thresholds across Emirates risk locking in lower performance baselines even though higher-performing models are already technically feasible (Rodriguez-Ubinas et al., 2020; Locke et al., 2023).

A related issue is retrofit governance. Much of the literature on envelopes and stock performance implies that the greatest long-run gains will come not only from improving new construction but also from prioritizing the existing building stock. In the UAE, this requires practical screening methods, building-type clustering, and post-occupancy evidence that can identify where façade upgrades, solar control, control systems, or mixed-mode opportunities will deliver the largest returns. The value of approaches such as façade-based energy estimation is that they help connect city-scale observation to investment prioritization. This matters because operational decarbonization is ultimately a stock problem as much as a design problem; demonstration buildings alone cannot move the whole urban baseline (Yang & Choi, 2015; Ji et al., 2022; Balaras et al., 2000).

The strongest synthesis of the operational literature is therefore a design hierarchy: reduce heat gains through urban form and envelope design; exploit climate-appropriate passive or mixed-mode opportunities;

integrate active systems and renewables in thermally robust ways; and govern all of this through harmonized standards and verified post-occupancy performance. Table 2 condenses these operational levers.

Table 2. Operational decarbonization levers for hot-arid and UAE-relevant built environments

Lever	What the literature shows	Climate relevance in hot-arid settings	Key trade-off or risk	Strategic implication for the UAE	Ref.
Orientation and solar control	Building orientation, glazing placement, and shading strongly influence cooling demand and glare	Critical because solar gains dominate comfort and cooling loads	Poorly managed glass-heavy design can erase gains from efficient equipment	Move solar control from optional feature to code-level design requirement	Friess and Rakhshan (2017); Salameh and Touqan (2022)
Envelope insulation and U-value control	Insulation and opaque envelope performance remain central and become more important under warming futures	Essential for limiting conductive gains and stabilizing interiors	Over-insulation without climate tuning can create diminishing returns in cooling-dominant buildings	Use future-climate-responsive envelope targets rather than static present-day assumptions	Pajek et al. (2022); Sadineni et al. (2011)
Natural and mixed-mode ventilation	Can significantly reduce energy demand in appropriate typologies and operating regimes	Useful where seasonal or diurnal opportunities exist and where design allows controlled airflow	Comfort, air quality, and humidity management can constrain applicability	Prioritize typology-specific mixed-mode strategies rather than generic prescriptions	Friess and Rakhshan (2017); Rahiminejad et al. (2022)
Urban morphology and shading context	Surroundings and urban geometry materially affect building demand and cooling intensity	Highly relevant because district-scale form shapes outdoor and indoor thermal stress	Building-only simulation can underestimate urban heat and shading effects	Integrate urban-scale modeling into city decarbonization and retrofit planning	Ji et al. (2022); Andersson-Sköld et al. (2015)
BIPV and active façades	Renewable façades can improve carbon performance when cooling and cavity dynamics are managed	Strong relevance due to high solar resource	Thermal degradation and maintenance can reduce expected performance	Couple renewable envelopes with passive cooling design and operational monitoring	Benzarti et al. (2022); Rodríguez-Gallegos et al. (2018)
Performance governance and code alignment	Building codes strongly shape mainstream uptake of efficiency measures	Essential because cooling loads are structurally embedded in the market	Fragmented thresholds weaken diffusion and benchmarking	Harmonize code ambition and link standards to verified performance data	Rodriguez-Ubinas et al. (2020); Locke et al. (2023)

Operational evidence also carries a temporal governance lesson. In much of the Gulf, design and regulation historically optimized buildings against market conventions rather than against future climate risk. The newer literature suggests that this approach is increasingly untenable. Future-climate-responsive envelopes, district-scale shading strategies, and stock-level prioritization tools should be treated as strategic planning instruments rather than specialist research outputs. The relevance of this point for the UAE lies in lock-in: buildings erected today will shape electricity demand, retrofit burdens, and heat exposure for decades. That makes early passive design a form of risk prevention, not just a route to efficiency (Pajek et al., 2022; Ji et al., 2022; Rodriguez-Ubinas et al., 2020).

The operational literature does not support incrementalism. It supports a redesign of the performance baseline itself. For the UAE, the policy question is no longer whether passive design, envelope refinement, and urban-scale analysis matter. The evidence already says they do. The real question is whether they will be treated as core decarbonization infrastructure rather than as discretionary upgrades layered onto cooling-intensive development.

6. Embodied carbon, life-cycle assessment, and circular material transitions

A second major shift in the supplied literature is the movement away from a purely operational understanding of sustainable buildings. Earlier "green building" discourse often implied that lower operating energy was a sufficient proxy for environmental quality. The life-cycle literature directly challenges that assumption. Khasreen et al. (2009) and López-Mesa et al. (2009) show that impacts are distributed across production, construction, operation, maintenance, and end-of-life, and that structural choices can materially change environmental outcomes. For the UAE, where rapid urbanization has historically privileged construction speed and volume, this is especially important. Efficient operation can coexist with carbon-intensive material pathways unless whole-life methods are used from the beginning.

The relevance of whole-life thinking becomes clearer when the LCA literature is read alongside broader mitigation and manufacturing work. Lucon et al. (2014) position buildings as a major mitigation domain whose opportunities span both demand reduction and material transitions, while Rosen and Kishawy (2012) argue that sustainable manufacturing depends on integrated concepts and practices rather than isolated substitutions. These perspectives support a practical conclusion for the UAE: embodied carbon reduction is not simply about selecting "better materials" at the margin. It requires earlier carbon-conscious decisions about structure, procurement, durability, repair, and waste, as well as more credible information systems for comparing alternatives (Lucon et al., 2014; Rosen & Kishawy, 2012).

Li et al. (2020) deepen this by modeling carbon as layered flows and loops rather than a single-point emissions problem. Although their case is outside the UAE building sector, the conceptual lesson is highly transferable: carbon neutrality claims become more credible when operational emissions, embodied emissions, circular flows, sequestration potentials, and residual burdens are distinguished rather than collapsed into an undifferentiated "net-zero" label. Vela et al. (2022) add another refinement by showing that whole-life analysis changes once hazards and end-of-life management are incorporated. This matters because climate resilience and decarbonization are often studied separately, even though fragile or short-lived assets may perform poorly under a risk-adjusted life-cycle view.

Circularity strengthens the same argument. Gooroochurn's (2022) circular homes framework is valuable because it translates energy, water, and material interdependence into a household-scale narrative that is easier for users and communities to act upon. This is relevant to the UAE because circularity often fails when it remains confined to professional rhetoric or backend waste management. In a fast-growing urban system, design-for-disassembly, adaptability, service-life extension, and reuse-ready procurement are more meaningful than generic circularity claims. The literature also warns against over-complex, equipment-heavy, or maintenance-intensive solutions that achieve marginal operational improvements at disproportionate embodied cost (Khasreen et al., 2009; Gooroochurn, 2022; Salameh & Touqan, 2022).

Whole-life assessment also has an ethical function. It reveals hidden burden shifting across time and population groups. If carbon-intensive materials are locked into today's development under the banner of efficient operation, then some of the burden is simply transferred to future mitigation efforts, future retrofit needs, or future adaptation costs. For that reason, whole-life carbon should be treated not only as a technical tool but as an instrument of fairness. Table 3 summarizes the literature on LCA, circularity, and nexus-oriented material strategy.

Table 3. Life-cycle, circularity, and water-energy-material nexus strategies in the literature

Strategy domain	Main contribution of the literature	Decarbonization value	Co-benefits for resilience or resource security	Main implementation barrier	Ref.
Life-cycle assessment in building design	LCA enables comparison of materials, systems, and whole building scenarios beyond operational use	Reveals hidden embodied impacts and supports early-stage decision making	Can improve procurement transparency and end-of-life planning	Limited data comparability and sparse localized inventories	Khasreen et al. (2009); López-Mesa et al. (2009)
Structural system selection	Alternative structural systems can materially change environmental outcomes	Reduces embodied impacts through better structural choices and possible prefabrication	May improve construction efficiency and reduce waste	Cost, familiarity, and supply-chain lock-in	López-Mesa et al. (2009); Vela et al. (2022)
Circular carbon and circular economy approaches	Carbon flows should be understood as loops, stocks, and sinks rather than as single-point emissions	Improves the credibility of carbon-neutrality planning	Supports material recirculation and long-term systems thinking	Complexity of modeling and accounting conventions	Li et al. (2020); Gooroochurn (2022)
Sustainable manufacturing and procurement	Material sustainability depends on upstream production systems and design practices	Reduces embedded emissions before project operation begins	Encourages industrial innovation and cleaner supply chains	Fragmented standards and weak procurement signals	Rosen and Kishawy (2012); Müller et al. (2020)
Hazard-aware whole-life analysis	Climate and hazard exposure alter long-term environmental and economic outcomes	Prevents misleading low-carbon claims based on short or idealized scenarios	Supports more durable and adaptable assets	Data intensity and methodological complexity	Vela et al. (2022); Pörtner et al. (2022)
Household-scale circularity framing	Homes can be used to communicate energy-water-material interdependence and behavior change	Connects circularity to lived practice rather than expert-only metrics	Builds social legitimacy and local climate literacy	Requires context-specific translation and sustained engagement	Gooroochurn (2022); Abuzaid et al. (2022)

A further implication concerns market signaling. In many rapidly urbanizing settings, embodied carbon remains weakly visible because procurement still privileges first cost, delivery speed, and compliance with minimum functional requirements. The supplied literature suggests that this invisibility distorts decision making. Once structural alternatives, service-life assumptions, and end-of-life pathways are compared systematically, the environmental significance of early design choices becomes much harder to ignore. For the UAE, localized datasets and benchmark disclosure would therefore have policy value beyond research. They would help normalize whole-life reasoning across developers, consultants, and regulators and would reduce the tendency to treat carbon accounting as an after-the-fact reporting exercise (Khasreen et al., 2009; López-Mesa et al., 2009; Vela et al., 2022).

The main implication is straightforward: embodied carbon is no longer a secondary chapter in built environment decarbonization. In the UAE context, it is one of the principal tests of whether low-carbon claims are structurally credible or only operationally partial.

7. Water, renewables, and the energy-water-material nexus in arid urban decarbonization

The supplied literature makes it clear that arid built environments cannot be decarbonized through energy analysis alone. Water systems, renewable systems, materials, and digital coordination are interdependent, and the UAE exemplifies this dependence. The anchor article by Locke et al. (2023) already emphasized the integration of energy, water, and waste; the broader dataset strengthens that direction by showing that resource silos conceal both trade-offs and opportunities (Locke et al., 2023; Gooroochurn, 2022; Zhou et al., 2020). Atmospheric water harvesting reviews are particularly important because they expand the range of building- and district-scale water strategies available to arid urban systems. Across Wahlgren (2001), Zhou et al. (2020), and Thavalengal et al. (2023), the key lesson is that water harvesting from air has progressed from conceptual curiosity to a technically differentiated field shaped by local humidity, temperature, material selection, and system design. These technologies are unlikely to displace large-scale desalination in the near term, but they matter because they diversify resilience options and can reduce dependence on centralized, energy-intensive water supply in selected contexts.

At the same time, the literature does not support a simplistic decentralized-versus-centralized framing. Infrastructure updates such as the DEWA SWRO development indicate that large-scale water systems are also evolving toward lower-carbon operation (Davids, 2022). The more useful conclusion is portfolio-based: future UAE decarbonization should combine more efficient desalination, building-scale demand reduction, atmospheric capture where appropriate, and renewable-powered treatment or purification pathways. Irshad et al. (2021) reinforce this by showing the potential of advanced solar-driven steam generation for freshwater production, highlighting that decentralized water-energy innovation is advancing beyond conventional pairings of photovoltaics and desalination.

Renewable integration literature adds a similar systems lesson. BIPV and active façade studies show that renewable systems perform best when their thermal behavior, cavity airflow, orientation, and maintenance needs are actively managed (Benzarti et al., 2022; Rahiminejad et al., 2022; Rodríguez-Gallegos et al., 2018). In other words, high solar resource alone does not guarantee strong decarbonization value. Renewable deployment must be envelope-aware and climate-responsive. The same logic applies to smart systems. Kaklauskas and Gudauskas (2016) and Dwivedi et al. (2022) suggest that digital systems can help reveal and coordinate energy-water-material interactions, but only if they are judged by real system benefit rather than by symbolic "smartness."

The nexus perspective also changes how resilience is conceived. Instead of asking whether a single technology can make a building self-sufficient, it asks how different systems can reduce dependency on vulnerable supply chains and improve operational flexibility during stress. In the UAE context, this can include coupling efficient envelopes with lower water demand, integrating renewables where thermal conditions support them, using digital systems to reveal resource interactions, and exploring decentralized water options for specific applications rather than as universal replacements. Such an approach is more realistic than self-sufficiency narratives and better aligned with the infrastructural scale of Gulf urbanism (Zhou et al., 2020; Davids, 2022; Dwivedi et al., 2022).

The broader nexus insight is therefore not that every building should become a self-sufficient micro-utility. It is that policy and design should stop assessing carbon performance in a single silo. A project may cut cooling demand while increasing water use, or install renewable systems while adding embodied and maintenance burdens, or digitize operations while generating rebound effects. Nexus thinking is a discipline for making these interactions visible, especially in water-constrained urbanism. Table 3 already captured the key strategy domains; in practice, the UAE implication is to treat water as a carbon variable, renewables as thermally conditioned systems, and digitalization as a coordinating layer whose value must be demonstrated rather than assumed.

8. Occupants, vulnerability, adaptation, and climate justice

The supplied studies also show why built environment decarbonization cannot be explained through physical performance metrics alone. Climate risk is experienced through housing, infrastructure, and urban exposure, but adaptive capacity is socially uneven. A technically sophisticated decarbonization strategy that ignores those inequalities is unlikely to be ethically credible or politically durable (Pörtner et al., 2022; Ehsan et al., 2022).

Abuzaid et al. (2022) are central in the UAE context because they show that sustainability perceptions among residential occupants vary significantly by gender, education, employment, and income. This matters well beyond residential attitudes. It means that retrofit policies, pricing mechanisms, disclosure requirements, and low-carbon housing measures will be interpreted through unequal social positions. Occupant perception is therefore not a soft add-on to technical policy. It is part of implementation feasibility and public legitimacy.

The justice dimension becomes sharper when this work is read alongside climate-vulnerability and adaptation studies. Ehsan et al. (2022) show that vulnerability emerges from the interaction of exposure, sensitivity, and adaptive capacity, while Andersson-Sköld et al. (2015) demonstrate the value of integrated adaptation assessment that accounts for heat, flooding, air quality, emissions, resource use, and public perception. These findings are transferable to the UAE even where the case studies are not local. They suggest that decarbonization should be judged partly by whether it improves access to thermally safe housing, reduces dependence on inefficient buildings, and avoids maladaptive solutions that solve one problem while worsening others.

This social perspective also reshapes the meaning of comfort. If modern urbanism normalizes sealed, fully conditioned interiors as the only acceptable comfort regime, then decarbonization becomes socially harder because everyday expectations are locked around energy-intensive norms. Vernacular and passive design studies suggest another possibility: comfort can be broadened through shading, air movement, compactness, and urban form rather than through mechanical compensation alone (Salameh & Touqan, 2022; Fernandes et al., 2014; Friess & Rakhshan, 2017).

Community-oriented work such as Gooroochurn (2022) further implies that participation matters. Transition is more durable when households understand how energy, water, and materials interact in daily life.

This justice framing matters for policy sequencing as well. Measures that appear rational in aggregate, such as stricter efficiency requirements or changes in utility pricing, can create uneven burdens if they are not accompanied by retrofit support, targeted communication, and clear public explanation. The literature does not provide a complete UAE distributional model, but it does provide enough evidence to reject the assumption that technical standards alone guarantee equitable outcomes. A socially credible decarbonization pathway needs both performance ambition and institutional sensitivity to who can comply, who can invest, and who remains exposed when markets underdeliver (Abuzaid et al., 2022; Ehsan et al., 2022; Kuh, 2017).

Climate justice should therefore be treated as an organizing principle of UAE built environment decarbonization. The relevant questions are practical: who gains access to efficient and climate-safe housing; who bears the burdens of high cooling dependence; who is left exposed to rising risk; and whether transition measures are legible enough to attract public support rather than passive compliance. A top-tier review must keep those questions inside the core framework rather than confining them to a concluding social appendix.

9. An integrative framework and research agenda for the next generation of UAE built environment decarbonization

The synthesis above points toward an integrative framework in which five layers must be aligned: governance and accountability; passive-first urban and building design; whole-life carbon and circularity; resource nexus coordination; and social legitimacy and justice. The framework is nexus-based because it connects systems that are usually separated in policy and design practice, and ethically explicit because it evaluates success not only by carbon reductions but also by robustness, fairness, and adaptive credibility.

At the governance layer, COP-linked ambition and national climate planning need translation into measurable built environment obligations such as future-climate code thresholds, whole-life carbon reporting, adaptation criteria, and post-occupancy disclosure (Wang et al., 2022; Kuh, 2017; Locke et al., 2023). At the passive-first layer, the literature strongly favors urban morphology, shading, solar control, and envelope design as the basis of low-carbon performance in hot-arid settings (Pajek et al., 2022; Hong et al., 2022; Salameh & Touqan, 2022). At the life-cycle layer, the main need is localization: UAE-specific embodied carbon datasets, structural benchmarks, and procurement mechanisms that reward durability, adaptability, and disassembly-ready design (Khasreen et al., 2009; López-Mesa et al., 2009; Vela et al., 2022).

The resource nexus layer requires joint thinking about energy, water, waste, materials, and digital coordination. The literature suggests that atmospheric water harvesting, solar-driven purification, desalination upgrades, BIPV, and waste valorization all have relevance, but only when assessed for context fit, maintenance demands, and life-cycle benefit rather than novelty alone (Zhou et al., 2020; Irshad et al., 2021; Benzarti et al., 2022; Curry & Pillay, 2012). The justice layer requires much stronger empirical work on perception, affordability, retrofit acceptance, and climate risk distribution inside the UAE, building on Abuzaid et al. (2022) but extending toward policy uptake and differentiated vulnerability.

This framework also clarifies the main conceptual risks. The first is techno-solutionism: assuming that smart controls, BIPV, desalination upgrades, or atmospheric harvesting can compensate for poor urban form or weak envelopes. The second is operational reductionism: presenting efficient operation as proof of sustainability while ignoring embodied impacts and end-of-life burdens. The third is symbolic governance: multiplying pilot projects and commitments without creating mainstream code and procurement change. The fourth is social abstraction: talking about resilience without identifying who remains exposed, who can adapt, and who can afford the transition. Table 4 distills these forward priorities for research and practice.

Table 4. Integrative research and policy agenda for next-generation decarbonization of the UAE built environment

Dimension	What the literature indicates	Ethical or policy significance	UAE-focused implication	Priority action for research and practice	Ref.
Governance and accountability	COP-linked ambition is growing, but implementation and metric translation remain decisive	Climate promises without enforceable building metrics risk symbolic action	Need stronger links between climate plans, building codes, and verified performance	Develop whole-life and adaptation-linked reporting requirements for buildings and districts	Wang et al. (2022); Kuh (2017); Locke et al. (2023)
Future-climate-responsive design	Passive measure relevance changes under warming scenarios	Designs optimized for current weather may become maladaptive later	UAE standards should be tested against projected hotter futures	Build future-climate archetype libraries and district simulations for UAE typologies	Pajek et al. (2022); Hong et al. (2022); Ji et al. (2022)
Whole-life carbon and circularity	Structural and material choices shape environmental outcomes over entire service lives	Prevents hidden burden shifting across time and phases	UAE needs localized embodied carbon data and circular procurement pathways	Introduce early-stage LCA, design-for-disassembly, and benchmark datasets	Khasreen et al. (2009); López-Mesa et al. (2009); Vela et al. (2022)
Nexus infrastructure	Water, renewable energy, waste, and digital systems are interdependent	Resource silos can create rebound effects and missed synergies	Arid urbanism requires joint energy-water planning rather than stand-alone efficiency measures	Test integrated building-to-district scenarios for water capture, desalination efficiency, BIPV, and waste valorization	Zhou et al. (2020); Thavalengal et al. (2023); Curry and Pillay (2012)
Social legitimacy and justice	Occupant perception and adaptive capacity vary significantly across groups	Transition durability depends on fairness and public acceptance	Policy design should account for income, education, and vulnerability differences	Expand UAE social research on retrofit acceptance, thermal expectations, and climate risk exposure	Abuzaid et al. (2022); Ehsan et al. (2022); Gooroochurn (2022)
Demonstration-to-mainstream transition	Flagship cases can inspire but do not guarantee diffusion	Exemplars must become learning platforms rather than symbolic exceptions	UAE demonstration projects should feed directly into code reform and procurement standards	Use pilot projects to generate open performance data and replicable implementation protocols	Locke et al. (2023); Rogmans (2025); Rodriguez-Ubinas et al. (2020)

Taken together, these priorities suggest that the UAE is well positioned to move from demonstration-based sustainability toward system-level transition design. The country has strong strategic visibility, a large portfolio of new development, and an increasingly explicit climate policy environment. Those advantages can only be translated into durable built environment decarbonization, however, if research, regulation, and project delivery are linked more tightly than in the past. Future-climate archetypes, open performance data, whole-life benchmarks, and district-scale nexus scenarios would all help convert isolated learning into repeatable governance capacity (Locke et al., 2023; World Green Building Council, 2022; Rogmans, 2025).

One reason this agenda is plausible is that the supplied literature already covers the full chain from principles to implementation. It includes foundational climate framing, UAE-specific passive design evidence, stock and code analysis, life-cycle and circularity research, water and renewable innovations, and studies of perception and vulnerability. What is still missing is not awareness of the problem, but tighter integration among these strands in research design and policy practice. That integration is precisely what a shorter, more strategic review should clarify: the UAE does not need to choose between mitigation, resilience, and ethics as separate agendas. The literature increasingly shows that the most effective pathways are those that align them in the same design and governance decisions (Locke et al., 2023; Wang et al., 2022; Khasreen et al., 2009; Abuzaid et al., 2022).

The agenda that follows from Table 4 is practical. It includes building future-climate archetype libraries for UAE typologies, producing localized whole-life carbon benchmarks, testing integrated district-scale energy-water scenarios, strengthening public-facing sustainability literacy, and using pilot projects as open learning platforms rather than as isolated showcases. The key research contribution of this review is therefore twofold: it updates the earlier UAE decarbonization discussion with recent literature and it shows that environmental ethics provides a useful connective logic across technical, infrastructural, and social evidence.

10. CONCLUSION

This review has condensed and updated the supplied evidence base into a broader account of UAE built environment decarbonization. The central conclusion is that the sector should not be treated as an energy-efficiency problem alone. It is a coupled challenge involving operational carbon, embodied carbon, water dependence, urban heat exposure, governance quality, and social legitimacy. The post-COP framing remains useful because it clarifies the accountability context, but the literature shows that real progress depends on translation: from high-level ambition to passive-first design, stronger codes, whole-life accounting, climate-adaptive envelopes, integrated resource systems, and socially credible implementation (Locke et al., 2023; Wang et al., 2022; Alayza, 2022).

The literature also implies that sequencing will matter. Passive-first design and stronger codes can reduce future lock-in; whole-life accounting can improve the carbon quality of current construction; nexus thinking can reduce infrastructure inefficiencies; and social research can make policy uptake more robust. When these elements are treated sequentially and institutionally rather than as one-off sustainability gestures, they reinforce each other. That is the deeper significance of environmental ethics in this review. Ethics is not presented as a parallel normative commentary, but as a criterion for judging whether the transition is avoiding burden shifting, increasing public resilience, and building legitimate capacity for long-term adaptation (Mann, 2009; Pörtner et al., 2022; Gooroochurn, 2022).

Across the evidence, four messages stand out. First, passive and envelope measures remain foundational in hot-arid contexts and should be treated as core infrastructure rather than optional refinement. Second, whole-life assessment is essential because operational gains can be offset by material intensity, short service lives, or uncounted end-of-life burdens. Third, water, renewables, waste, and digital systems must be assessed as part of a nexus rather than in separate silos. Fourth, decarbonization will only be durable if it addresses perception, vulnerability, and justice as core variables rather than peripheral concerns (Friess & Rakhshan, 2017; Khasreen et al., 2009; Zhou et al., 2020; Abuzaid et al., 2022).

For the UAE, the practical implication is clear: a credible next phase of decarbonization should normalize future-climate-responsive design, whole-life carbon methods, stronger code alignment, water-aware carbon strategy, and community facing transition governance. If those shifts occur, the UAE can move from exemplary projects toward a more systemic low-carbon urban model. If they do not, decarbonization risks remaining partial ambitious in language but insufficiently transformative in structure. Environmental ethics becomes operational precisely at this point: not as abstract moral vocabulary, but as the discipline that keeps the transition from becoming narrow, symbolic, or unjust.

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