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A multi-level governance framework to accelerate the adoption of net-zero carbon and net-zero water buildings in developing countries

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ABSTRACT

South Africa faces escalating energy insecurity and water scarcity, rendering the transition to net-zero carbon and net-zero water buildings indispensable. However, their adoption remains slow and fragmented. This study applied a Multi-Level Perspective to examine how landscape, regime and niche dynamics operate across macro (national), meso (provincial and industry) and micro (municipal and project) levels, shaping net-zero carbon and net-zero water building adoption. Using qualitative data from semi-structured interviews with facility managers, municipal officials and built environment professionals, findings were thematically analysed using NVivo. Results highlight interdependent barriers across governance levels including policy misalignment, weak financial incentives, uneven institutional capacity, skills shortages and operational constraints. Integrating these insights with sustainability transitions literature, the study proposes the Net Zero Building Acceleration Framework, which elucidates cross-level interdependencies and key leverage points. The framework offers a context sensitive route for accelerating adoption through coordinated, governance aligned interventions in South Africa and similar developing context.

KEYWORDS

Net-zero carbon buildings, Net-zero water buildings, Multi-level governance, Energy and water resilience, Sustainability transitions, Built environment, Decarbonisation framework

INTRODUCTION

The global built environment is undergoing a transition towards low carbon, resource efficient development in response to climate change, rising energy costs, and intensifying water scarcity. Buildings account for approximately 36% of global energy consumption and a significant share of energy related emissions [1], positioning the sector at the centre of sustainability transitions. Within this context, net zero carbon (NZC) and net zero water (NZW) buildings have emerged as critical strategies. NZC buildings minimise operational emissions through efficiency, renewable energy and demand side management [2], [3], while NZW buildings reduce reliance on municipal water systems through efficiency, reuse and circular water practices [4]. Increasingly, these approaches are recognised not as isolated performance targets, but as integrated pathways for enhancing environmental performance and long-term resource resilience.

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Despite this global momentum, adoption in developing countries remains uneven and slow. South Africa illustrates this paradox. Although the need for resource efficient buildings is acute, only a limited number of buildings have achieved net-zero certification in recent years [5], [6]. The country faces persistent electricity supply constraints, a carbon intensive energy mix, and recurrent load shedding, alongside growing water scarcity and infrastructure degradation[7]. These constraints heighten the relevance of NZC and NZW buildings, yet adoption remains constrained. Existing studies attribute this to high capital costs, weak incentives, limited technical capacity, and policy inconsistency [8]. However, much of the literature remains focused on technical performance, regulatory instruments such as SANS 10400-XA and voluntary certification systems [5], with limited attention to how governance structures shape implementation outcomes.

Emerging international evidence suggests that successful net-zero transitions depend not only on technological capability, but on the alignment of governance system across multiple levels [4]. Coordinated policy framework, institutional capacity, and local implementation mechanisms have enabled more rapid adoption in parts of Europe and Asia. In contrast, South Africa's built environment is characterised by fragmented governance, where responsibilities are distributed across national regulators, provincial authorities, municipalities and industry actors, often with weak coordination and unclear mandates [8]. This fragmentation constraints the translation of policy intent into implementation and limits the scaling of net-zero practices. There is therefore a need to move beyond identifying barriers towards developing a governance-based, system-level pathways for acceleration adoption.

Responding to this gap, this study develops the Net-Zero Building Acceleration Framework (NZABF), a multi-level governance model designed to support the scaling of NZC and NZW buildings in South Africa and similar developing contexts. Grounded in qualitative insights from built environment professionals, the framework synthesises empirically identified barriers and enablers with sustainability transitions theory to articulate how interactions across national, provincial and municipal levels shape adoption outcomes.

This paper makes three contributions. First, it integrates NZC and NZW buildings into a unified analytical framework, addressing a gap where these domains are typically examined in isolation. Second, it advances sustainability transitions scholarship by operationalising the multi-level perspective through a governance aligned lens, positioning net-zero adoption as a coordination challenge rather that a purely technical one [9]. Third, it offers a practical, context specific yet transferable framework that identifies leverage points and informs the sequencing of interventions in resource constrained environments.

Accordingly, the study is guided by the following research question:

How can multi-level governance framework be developed to accelerate the adoption of net-zero carbon and net-zero water buildings in South Africa, based on empirically identified barriers, enablers and systemic gaps.

The remainder of the paper is structured as follows. The literature review synthesises global and local insights on net-zero buildings and governance dynamics. This is followed by the methodology and empirical findings, which inform the development of the NZBAF and its associated implementation pathway. The paper concludes by discussing the implication for policy, practice and future research.

LITERATURE REVIEW

This literature review synthesises key perspectives on the transition toward net-zero buildings by integrating insights on net-zero carbon (NZC) and net-zero water (NZW) systems, their adoptions dynamics, and the governance structures shaping implementation. It begins by conceptualising NZC and NZW buildings and highlighting the value of an integrated approach, before examining the key barriers and enablers influencing adoption. These dynamics are then situated within multi-level perspectives (MLP) and multi-level governance (MLG) frameworks to explain how interactions across national, provincial and municipal levels shape transition outcomes. Drawing on international experience and the South African context, the review culminates in the conceptual foundations of the Net-Zero Building Accelerations Framework. (NZBAF).

Integrated perspectives on net-zero buildings

NZC buildings are defined as facilities that minimise operational energy demand and offset the remaining loads through renewable energy, thereby reducing emissions to the lowest achievable level [10]. NZW budlings similarly aim to balance water demand through harvesting, recycling and reduced potable water use [11], [12]. While often treated separately, increasing evidence supports an integrated approach due to the strong interdependencies between energy and water systems [12]

This integration is particularly relevant in water stressed and carbon intensive contexts, where water processes such as pumping and treatment are energy intensive, and energy systems influence water efficiency outcomes [12]. Addressing these systems jointly enables synergistic performance gains while avoiding unintended trade-offs, such as increased energy use from advanced water treatment technologies or higher water demand from certain thermal strategies [13]. Integrated approaches also enhance resilience, as climate projections indicate simultaneous increases in heat stress and water scarcity. Design strategies such as passive cooling, rainwater harvesting and renewable powered water systems therefore provide dual benefits by reducing dependencies on constrained infrastructure [13].

Overall, an integrated NZC-NZW perspective supports circular resource management and enables buildings that are simultaneously low-carbon, water efficient and resilient, particularly in developing country contexts.

Barriers and enablers of net zero building adoption

Despite these advantages, the adoption of NZC and NZW buildings remains constrained by interrelated financial, technical and institutional barriers [14]. High upfront capital costs, long payback period and the limited access to green finance reduce investment incentives, particularly in emerging markets [15]. Technical constraints, including limited design expertise, shortages of specialised contractors and insufficient operational capacity, further undermine implementation readiness [16].

Institutional and regulatory conditions compound these challenges. Fragmented policies, weak incentives and inconsistent enforcement reduce confidence in net-zero investment, while procurement inefficiencies and municipal capacity constraints slow implementation [17] . The persistence of these barriers reflects the stabilising influence of existing socio-technical regimes, which reinforce established practices and limit the diffusion of innovation [6].

At the same time, global research identifies key enablers, including certification systems, financial incentives, and clear performance standards which help reduce uncertainty and legitimise emerging technologies.

Multi-level governance and sustainability transitions

The MLP conceptualises transitions between landscape (macro), regime (meso), and niche (micro) levels [9], [18]. Landscape pressures include broad forces such as climate change and macroeconomic conditions, while regimes represent dominant institutional arrangement that stabilise existing systems. Niches provide protected spaces for experimentation and innovation. Transitions occur when these levels align, enabling niche innovations to scale and reshape regimes.

Complimenting this, MLG emphasise the importance of coordination across governance tiers. In this study, MLP is operationalise through governance structures, where the landscape aligns with national policy, the regime with provincial coordination, and the niche with municipal implementation. This alignment enables a more precise understanding of how authority, capacity and decision making are distributed across the system. Intermediary actors, including municipalities and professional bodies, play a critical role in translating policy into practice and enabling local adoption [19].

International lessons and the South African context

International evidence shows that successful net-zero transitions rely on coordinated policy mixes combining regulation, incentives and market mechanisms [14]. High performing systems also emphasise benchmarking, performance disclosure and demonstration projects, which reduce uncertainty and support scaling through learning and market confidence.

In South Africa, however, progress is constrained by institutional fragmentation, limited municipal capacity and weak policy alignment. Skills shortages, financial constraints and infrastructure challenges further inhibit adoption, reinforcing risk averse response among actors [16]. These conditions highlight that the transition challenge is not primarily technological, but institutional and governance related.

Towards a net-zero building acceleration framework (NZBAF)

Building on these insights, the NZBAF conceptualises net-zero adoption as a multi-level governance challenge requiring alignment across national, provincial and municipal levels. Drawing from MLP and MLG, the framework emphasises that niche-level experimentation can only scale when supported by coherent national policy and effective provincial coordination. In resource constrained context, accelerating NZC and NZW adoption therefore depends on resolving institutional misalignment, strengthening capacity and enabling coordinated actions across governance tiers.

Integrating empirical insights with transition theory, the NZBAF provides a structured basis for understanding how governance dynamics shape adoption and for identifying targeted intervention points to accelerate net-zero building transitions in South Africa and similar developing economies.

RESEARCH METHODOLOGY

Research design

This study adopted a qualitative, exploratory research design to examine a multi-level governance dynamic influencing the adoption of NZC and NZW buildings in South Africa. Qualitative methods are well suited to examining complex socio-technical transitions and governance structures where multiple actors, institutions and policy layers intersect [20]. The design enables an in-depth exploration of practitioner experiences and critically supports the identification of cross-level patterns and systemic constraints, consistent with the study's objective of developing a governance aligned, theory building framework.

Sampling and participants

Purposive sampling was used to identify participants with direct expertise in building energy and water management, green building implementation, municipal regulation and sustainability strategy. A total of 25 participants were invited to take part in the study based on their professional roles and experience in facility management, sustainability consultancy, municipal planning, engineering and real estate operations.

Of the 25 invited participants, 18 agreed to participate, resulting in a 72% response rate, which is acceptable for expert based qualitative studies.

Data collection

Data were collected through semi-structured interviews conducted. Online platform (Zoom) was used to facilitate access to geographically dispersed experts and ensure scheduling flexibility. Interviews ranged from 45 and 60 minutes, were audio recorded with consent, and later transcribed verbatim. The flexibility of semi-structured interviews allowed participants to elaborate on issues unique to their contexts while maintaining consistency across topics.

Data analysis

Data form 18 semi-structured interviews were analysed using a reflexive thematic analysis approach. After transcription, initial codes were generated inductively, focusing on recurring patterns related to energy water, technology, policy, behaviour, financial considerations and organisational dynamics. Codes were iteratively refined and grouped into broader thematic cluster through constant comparison, memo writing and cross-checking between transcripts. Themes were then organised according to MLP framework, macro (national), meso (provincial and industry) and micro (municipal) level clusters which enabled the classification of findings into interacting levels of influence. This analytical structure allowed the study to move beyond surface challenges and to unpack how systemic, organisational, and building level factors collectively hinder or enable net-zero adoption.

Methodological justification

The study adopted the MLP as its analytical framework to examine the adoption of NZC and NZW buildings because MLP is particularly suited to unpacking complete sustainability transitions that involve interacting technological, institutional and behavioural dimensions [21]. While MLP has traditionally been applied to analyse socio-technical change at an abstract systems level, recent scholarship has increasingly operationalised it within governance and policy implementation contexts, especially in the developing countries. In this study, the MLP is explicitly aligned with South Africa's three tier governance structure national, provincial, and municipal to empirically trace how landscape, regime, and niche dynamics shape net-zero implementation outcomes. This operationalisation enables a nuanced examination of cross-level interdependencies and governance induced constraints that are not readily captured through single level or category based analytical frameworks. Table 1 outlines how MLP was used to view the constraints in a three-tiered governance structure.

Table 1: Governance aligned MLP integrating three tier governance structure

MLP term	Governance scale	Meaning
Landscape (macro)	**National**	National policy, fiscal frameworks, codes, climate commitments shape the enabling environment
Regime (meso)	**Provincial**	Provinces mediate policy, oversee capacity, coordinate infrastructure and skills systems
Niche (micro)	**Municipal**	Municipalities are sites of experimentation, implementation, enforcement, and learning

Limitations of the study

This study is subject to several methodological limitations inherent in exploratory expert based qualitative research. First, the representation of other technical roles by a single respondent limits the capture of intra-professional variability and introduces the risk of over reliance on individual perspectives. This was mitigated through purposive sampling of highly experienced, cross-functional experts, many of whom operate across multiple roles and institutional contexts, as well as through thematic triangulation across respondents and alignment with existing literature to identify convergent patterns rather than privileged isolated views. Second, given the relatively small and interconnected expert community in net-zero construction, there is a possibility of shared epistemic orientations among participants. To address this, the study deliberately included participants from diverse organisational and functional backgrounds, while analytically treating convergence as indicative of systemic conditions and remaining attentive to divergence. Third, this study does not seek statistical validation or saturation within professional categories and is therefore not generalisable in a positivist sense. Instead, it is positioned as an exploratory, theory building enquiry, where findings are analytically generalised to system-level dynamics.

RESULTS

The findings are presented across three interrelated levels namely, landscape, regime and niche corresponding to macro, meso and micro scales, to reflect the complex layered nature of NZC/NZW implementation in South Africa. The landscape level (macro level) captures national scale and system level factors such as policy alignment, regulatory framework, infrastructure readiness, and economic or financial conditions. The regime (meso) level synthesises industry and organisational level influences, including sector capacity, technology availability, supply chain maturity and leadership or organisational culture. The micro level focuses on immediate building scale issues, including occupant behaviour, operations and maintenance practices, project level budgeting and technical integration challenges.

Themes at each level emerged from multiple participants and were supported by convening narratives accounts. This multi layered presentation ensures a comprehensive portrayal of how barriers, enablers and operational realities interact to shape the adoption of net-zero buildings in South Africa.

Profile and characteristics of participants

A total of 25 participants were invited and 18 participated in the study (72% response rate), comprising facility managers, municipal managers, sustainability consultants, architects, green building specialists and operations personnel with direct experience in energy and water management in the built environment. Table 2 below outlines the diversity of participants that represented both the public and private sectors, with work portfolios spanning commercial buildings, institutional facilities, mixed use development and large corporate assets. Their professional experience ranged from 5 to 20 years, offering a rich diversity of insights. This diversity allowed the study to capture perspectives from strategic decision makers, technical implementers, and operational staff contributing to a holistic understanding of net-zero carbon (NZC) and net-zero water buildings (NZW) adoption dynamics in the South African context.

Table 2: Profile and characteristics of participants

Participant ID	Role category	Sector	Years of experience	Province/ Metro
R1	Municipal manager	Local government	12	Johannesburg
R2	Facilities manager	Corporate	15	Johannesburg
R3	Sustainability specialist	Consultant	9	Cape Town
R4	Built environment practitioner	Architect	11	Durban
R5	Building standards and compliance	National standards and specification	18	Johannesburg
R6	Municipal official	Local government	7	Durban
R7	Deputy director	National government	20	Johannesburg
R8	Deputy director	National government	8	Durban
R9	Facilities manager	Corporate	14	Cape Town
R10	Building manager	National government	10	Cape Town
R11	Built environment practitioner	Architecture	7	Cape Town
R12	Housing compliance manager	National authority for building regulations	12	Johannesburg
R13	Built environment practitioner	Quantity surveying	8	Johannesburg
R14	Built environment practitioner	Project Management	14	Cape Town
R15	Built environment practitioner	MEP engineer	8	Durban
R16	Built environment practitioner	Electrical engineer	12	Johannesburg
R17	Sustainability specialist	Consulting	5	Johannesburg
R18	Municipal manager	Local government	6	Cape Town

Landscape (macro) level governance barriers

At the macro level, participants consistently raised weak enforcement which creates uncertainty for developers and limits large scale investment. Several participants emphasised that regulatory ambiguity around what constitutes a net-zero standard results in "*different interpretations across municipalities*" (R3), where others stressed the "*lack of a consistent national framework*" (R9) discourages firms from committing financial and technical resources. These findings align with global studies noting that policy clarity and aligned codes are essential accelerators of net-zero transitions in developing economies. Within the dataset, the convergence of views across respondents R3, R9, R11, R14 and R16 underscores that policy coherence remains a structural barrier, as summarised in Table 3.

Economic constraints featured prominently, with nearly all participants emphasizing the high upfront capital costs, budget limitations, and absence of financial incentives as major barriers to adoption. As respondents noted, "*upfront capital cost is the biggest reason* *developers avoid NZC*" (R1), and "*clients see net-zero as too expensive even when life-cycle costs are lower*" (R12). Several participants (R5, R8, R15) further indicated that South Africa lacks tax rebates, grants, and financing instruments commonly used to stimulate net-zero investments in other countries. These perceptions mirror evidence from developing regions where financial architectures are not yet aligned with national decarbonization goals. Participants also described infrastructure limitations including grid instability, loadshedding, water scarcity, and outdated municipal systems as significant barriers. As one respondent stated, "*NZC is hard when the grid itself is unstable*" (R2), while others linked water scarcity directly to NZW feasibility (R4, R13). These insights collectively show that macro-level structural conditions policy misalignment, financial system maturity, and foundational infrastructure readiness shape the feasibility of net-zero transitions. The detailed quotes and implications of these themes are summarized in Table 3.

Table 3. Landscape (macro) level barriers

Theme	Highlighted keywords	Verbatim Quotes (Multiple respondents)	Implication
Policy misalignment & regulatory gaps	**unclear policy, inconsistency, fragmented, weak enforcement**	**R3:** "The *policy is unclear* on what qualifies as net-zero, so municipalities *interpret it differently*."	Adoption stalls when regulatory signals are weak or contradictory.
		R9: "There is *no consistent national framework*, which makes firms hesitate to invest."	
		R11: "Our compliance processes are *fragmented* between water, energy and building codes."	
		R14: "Even where standards exist, *enforcement is weak*."	
		R16: "We need *harmonised regulations* that compel adoption."	
Economic constraints & high capital costs	**capital cost, budget constraints, financial risk, no incentives**	**R1:** "The *upfront capital cost* is the biggest reason developers avoid NZC."	National finance architecture does not yet support NZ building transitions.
		R5: "Local budgets cannot *absorb the financial risk* of new technologies."	
		R8: "We have *no financial incentives* like tax rebates or grants."	
		R12: "Clients see NZC as *too expensive*, even when life-cycle costs are lower."	
		R15: "Banks are *not yet willing to finance* NZC/NZW projects."	
Infrastructure limitations (Energy & Water)	**grid instability, water scarcity, capacity, inadequate infrastructure**	**R2:** "NZC is hard when the *grid itself is unstable*."	Systemic infrastructure weaknesses constrain net-zero viability.
		R4: "We face *extreme water scarcity*, so reliability is a barrier." **R5:** "Loadshedding"	
		R10: "Municipal systems have *limited capacity* for new green technologies."	
		R13: "Stormwater harvesting laws are outdated *infrastructure isn't ready*."	
		R18: "Weak infrastructure slows *scaling* of net-zero technologies."	

Regime (meso) level barriers

At the meso level, participants identified industry wide knowledge gaps and uneven capacity as significant impediments to the implementation of NZC/NZW practices. Respondents repeatedly emphasized that contractors, facility managers and organizational sustainability teams lack consistent understanding of net-zero principles, advanced modelling, and performance verification. As one participant noted, "*There is limited awareness among contractors on what NZC actually entails*" (R1), while others highlighted a "*skills gap in modelling, monitoring and verifying carbon*" (R6) and insufficient training on net-zero technologies (R9). These views align with international evidence showing that the maturity of technical capacity across the value chain strongly determines the rate at which net-zero standards diffuse through the built environment. Within this study, the convergence of responses (R1, R6, R9, R12, R17) demonstrates that industry preparedness remains uneven, limiting the sector's ability to normalize net-zero design and operational practices. These findings are summarized in Table 4.

Technological and supply chain constraints further illustrate the meso-level challenges facing the South African construction and facilities sectors. Participants described the limited availability, affordability, and maintainability of advanced energy and water technologies as major barriers, with several respondents stressing reliance on imported monitoring and sensing equipment (R5) and the scarcity of maintenance expertise (R8). As one respondent explained, "*The supply chain is not mature for NZ-specific materials*" (R13), while others noted that long lead times and high prices inhibit procurement of NZW systems (R18). These insights echo broader research indicating that local manufacturing ecosystems and technology supply chains in Global South contexts are still developing, creating uncertainty around long-term operability and technical support. A final meso-level factor concerned organizational culture and leadership readiness, where respondents highlighted that adoption often depends on executive commitment, prioritization, and willingness to invest in low-carbon innovation. As participants explained, "*Without leadership buy-in, sustainability stays symbolic*" (R3), and many organizations remain "*reactive, not innovation-driven*" (R10). These findings collectively underscore that industry structures and organizational behaviors play a decisive role in shaping adoption pathways, as detailed in Table 4.

Table 4. Regime (meso) level barriers

Theme	**Highlighted Keywords**	**Verbatim Quotes (multiple respondents)**	**Implication**
Industry awareness & Knowledge gaps	**awareness, capacity, skills gap, training**	**R1:** "There is *limited awareness* among contractors on what NZC actually entails." **R6:** "We have a *skills gap* in modelling, monitoring and verifying carbon." **R9:** "Most facilities teams *lack training* on net-zero technologies." **R12:** "Knowledge differs widely industry capacity is still *immature*." **R17:** "We need structured *industry upskilling programmes*."	Sector-wide knowledge deficits limit industry readiness.
Technological constraints & Supply chain challenges	**technology availability, supply chain, maintenance, import dependence**	**R2:** "Solar-battery systems are available but *still expensive* locally." **R5:** "We depend on *imported technology* for monitoring and sensing." **R8:** "Maintenance expertise is *scarce*, causing operational risks." **R13:** "The supply chain is *not mature* for NZ-specific materials." **R18:** "Lead times for NZW equipment are *too long*."	Industry ecosystems are not yet positioned to support NZ building deployment.
Organisational culture & Leadership readiness	**leadership drive, culture, prioritisation, institutional buy-in**	**R3:** "Without *leadership buy-in*, sustainability stays symbolic." **R7:** "Some companies still don't *prioritise carbon reduction*." **R10:** "The culture is reactive not *innovation driven*." **R14:** "Executives want evidence of *clear ROI* before adoption."	Leadership commitment determines whether organisations transition or resist change.

Niche (micro) level barriers

Micro-level barriers refer to internal, building level practices and decisions that directly affect the operational performance of Net Zero Carbon (NZC) and Net Zero Water (NZW) buildings. These barriers emerged strongly from the interview dataset, demonstrating how user behaviour, operational capacity, project-level financial decisions, technical integration constraints, and performance monitoring practices influence performance outcomes. The themes that emerged from the micro-level analysis are presented in Table 5, which synthesises highlighted keywords, multiple verbatim responses, and the practical implications for NZC and NZW performance. Across the 18 interviews, micro-level challenges were found to be the most recurrent and frequently cited barriers, indicating that even where macro- and meso-level frameworks exist, building performance is ultimately enacted at user, operations, and design-integration levels. Five strong themes were identified: (1) behavioural practices & occupant engagement, (2) operations & maintenance capacity, (3) project level financial decisions & value engineering, (4) technical integration at building level, and (5) data, monitoring & performance verification.

This theme emerged as one of the strongest micro-level concerns. Participants repeatedly linked building performance failures to user habits, system misuse, and low awareness of NZC/NZW operational requirements. Several respondents emphasised that despite having efficient technologies, "*user behaviour still leads to overconsumption*" (R2) and that occupants often "*override low-flow systems*" (R8). Table 5 reflects repeated mentions of habits, misuse, and poor engagement, signalling that technical interventions alone cannot achieve NZ targets. This finding highlights the need for comprehensive behaviour-change programmes and occupant training as central components of NZ implementation.

Operations and maintenance capacity was the most frequently referenced technical barrier. Respondents described skills gaps in maintenance teams, limited ability to read or interpret monitoring data, and inadequate calibration and troubleshooting practices. For example, R3 noted that faulty sensors remain unfixed due to "*lack of calibration skills*," while R6 explained that teams "*don't know how to interpret the data*." As Table 5 shows, these issues point to systemic weaknesses in operational readiness and technical competence. The results indicate that without targeted O&M upskilling, NZ systems tend to degrade, drift, or underperform over time. Project level decisions were reported as critical barriers affecting the final installed performance of NZ features. Participants highlighted how value engineering during tender stages often results in downgrading specifications, removing high-efficiency systems, or prioritising short-term cost savings. Respondents explained that "*net-zero features are the first to be cu*t" (R1) and that "*CAPEX dominates decisions*" (R12). Table 5 demonstrates recurrent keywords such as budget cuts, trade-offs, and life-cycle costs, underscoring how micro-level financial decisions undermine the long-term sustainability performance of buildings. Participants described significant challenges around integrating water- and energy-efficient technologies into both new and existing buildings. Several interviews pointed to compatibility issues, commissioning complexity, and design silos between mechanical, electrical, and water system specialists. R3 noted that systems "*don't integrate seamlessly*," while R7 highlighted that systems "*are often designed in silos*." As summarised in Table 5, the lack of coordinated design and optimisation processes weakens building-level system performance and limits the realisation of predicted NZC/NZW benefits. Weak performance monitoring culture was cited as a major contributor to the performance gap between predicted and actual energy and water use. Respondents explained that although many buildings have meters and sensors installed, the data is not analysed, not used for decision-making, or not linked to performance targets. As one participant put it: "*We collect data, but don't analyse it meaningfully*" (R2). Table 5 shows recurring concerns around underutilised data, immature verification practices, and weak tracking, indicating that performance feedback loops remain underdeveloped.

Overall, micro-level barriers reveal that NZC/NZW performance is significantly constrained by behavioural, operational, financial, and technical integration practices within buildings. While macro-level policies and meso-level organisational strategies are important enablers, the interviews strongly indicate that NZ performance success or failure is ultimately determined by building-level implementation and day-to-day practice. The five themes identified demonstrate the need for targeted user engagement, stronger O&M capacity building, life-cycle-based decision-making, improved technical integration processes, and robust performance monitoring frameworks.

Table 5. Niche (micro) level barriers

Theme	Highlighted Keywords	Verbatim Quotes (Multiple respondents)	Implication
Behavioural practices & Occupant engagement	**behaviour, habits, user engagement, misuse, awareness, energy culture, water-saving behaviour**	**R2:** "Even with efficient systems, *user behaviour* still leads to overconsumption." **R4:** "Staff *switch off sensors* because they think they interfere with comfort." **R8:** "We installed low flow taps, but *users override* them using manual bypasses." **R11:** "Occupants don't understand how their *daily habits affect targets*." **R13:** "We need *behaviour change programmes*, not only technology." **R17:** "Users are unfamiliar with the *energy culture* required for net-zero buildings."	NZ performance is highly dependent on occupant behaviour, requiring structured engagement programmes and long-term awareness interventions.
Operations & maintenance (O&M) capacity	**maintenance, skills, technical competence, monitoring, system failure, calibration, operational readiness**	**R1:** "Many systems fail because *maintenance teams aren't trained*." **R3:** "Faulty sensors remain unrepaired because we lack *internal calibration skills*." **R6:** "Monitoring systems show data, but teams *don't interpret* it effectively." **R10:** "We rely on consultants for routine tasks *internal capacity is too low*." **R12:** "Green infrastructure is installed, but the *O&M manuals are barely used*." **R15:** "Inadequate *operational readiness* undermines long-term system performance." **R18:** "O&M staff need *specialised competency* for water and energy systems."	Weak O&M capability is a critical point of system failure, undermining performance consistency and causing premature technology degradation.
Project-level financial decisions & value engineering	**budget cuts, trade-offs, value engineering, short-term cost decisions, life-cycle, specification downgrades**	**R1:** "Net-zero features are usually the first to be cut during *value engineering*." **R5:** "Clients push for *cheap short-term solutions* over sustainability." **R9:** "Developers *downgrade specifications* once tender prices increase." **R12:** "Long-term savings are rarely considered *CAPEX dominates decisions*." **R14:** "Consultants are pressured to remove *higher efficiency systems due to costs*." **R16:** "Life-cycle costing is not standard practice in our projects." **R18:** "We still work in a culture where *cost trumps performance*."	Project-level cost-driven decisions weaken net-zero performance, showing the need for mandated life-cycle costing and decision-making guidelines.
Technical integration at building level	**integration, compatibility, commissioning, design gaps, system optimisation, retrofit complexity**	**R3:** "Technologies don't always *integrate seamlessly*, commissioning becomes complex." **R6:** "Older buildings are *difficult to retrofit* for water efficiency." **R7:** "Energy systems and water systems are often *designed in silos*." **R11:** "Smart controls fail because *legacy equipment* cannot communicate with them." **R14:** "Initial commissioning is good, but *optimisation over time is weak*."	Technical integration barriers require integrated design teams, better commissioning standards, and dedicated optimisation processes.
Data, monitoring & performance verification	**monitoring, performance data, verification, underutilised data, performance gap, tracking**	**R2:** "We collect data, but *don't analyse it* meaningfully." **R5:** "There is a big *performance gap* between predicted and actual use." **R8:** "Meters exist but *no one tracks* whether targets are met." **R13:** "Verification of carbon and water metrics is still *immature*."	Performance gaps remain due to weak monitoring culture and underdeveloped data analysis practices.

		R17: "Post-occupancy data is *rarely used to adjust systems*."	

Integration of themes into the NZBAF Framework

The findings reveal a coherent, multi-level system of barriers that collectively shape the feasibility, pace, and quality of Net Zero Carbon (NZC) and Net Zero Water Building (NZW) adoption in South Africa. A multi-level structuring of the results into landscape, regime and niche (macro**,** meso**,** and micro**)** level lenses enable a conceptually clear and cogent understanding of how constraints interact across policy, industry, and building practice domains. This layered structure was not imposed a priori; rather, it emerged inductively through thematic convergence during coding. Interviews consistently revealed that challenges cluster at distinct yet interdependent levels of influence, which warranted a multi-level analytical framing.

At the landscaped (macro) level, themes such as *policy misalignment*, *regulatory fragmentation*, *infrastructure deficits*, and *high capital costs* illustrate how national systems create an enabling or constraining environment for NZ transitions. These barriers sit upstream, shaping incentives, institutional certainty, and market readiness. At the regime (meso) level, the data highlighted industry wide conditions including *knowledge gaps*, *technology availability*, *supply chain maturity*, and *leadership readiness* that either amplify or mitigate macro level pressures. Finally, the niche (micro) level revealed proximate drivers of performance, including *occupant behavior*, *O&M capacity*, *project level decision making*, *technical integration challenges*, and *performance monitoring practices*. These findings emphasize that NZ outcomes are enacted daily within buildings, making micro-level practices crucial for bridging the performance gap between design intent and operational reality.

This multi-level thematic structure became the analytical foundation for constructing the Net-Zero Building Acceleration Framework (NZBAF). Mapping each theme to a level of influence, the study was able to conceptualize NZ adoption not as a set of isolated technical problems but as a systemic socio-technical transition requiring coordinated action across different governance and operational layers. The NZBAF therefore synthesizes the empirical themes with international best practice and transition theory to propose integrated interventions across five domains policy and regulation**,** finance and incentives**,** industry capability**,** building level implementation, and performance verification.

Conceptually, the NZBAF positions landscape (macro) level reforms such as harmonized standards, targeted incentives, infrastructure upgrading as necessary but insufficient without simultaneous regime (meso) level strengthening such as professional training, supply-chain development, leadership commitment and niche (micro) level optimization such as behavioral engagement, operations and maintenance upskilling, integrated commissioning. The framework thus reflects the study's central conclusion that net-zero adoption is shaped by multi-level dynamics that must be addressed collectively rather than in isolation. Presenting the results in a macro, meso, microstructure allows the framework to visually and conceptually demonstrate these interdependencies, offering a robust and context specific model for accelerating NZC/NZW implementation in South Africa's built environment and other developing countries with similar challenges.

DISCUSSION OF RESULTS

This study set out to explain limited adoption of NZC and NZW buildings in South Africa despite growing policy commitments and global progress. The findings demonstrate that constraints to adoption are not isolated at the project or organisational level, but are systemically embedded across interacting governance tiers, reinforcing the view that net-zero transitions are fundamentally multi-level governance challenges rather than purely technological problems.

At landscape level (national), the results reveal fragmented regulatory frameworks, weakly coordinated policy instruments, and insufficient financial incentives create uncertain and inconsistent policy environment. Although national commitments to decarbonisation and water security are well articulated, they lack the coherence and enforceability required to provide clear direction to the market. This misalignment weakens credibility of policy signals and constraints downstream actors, limiting the ability of provincial institutions to coordinate industry transformation and capacity development. These findings align with transition literature emphasising that weak landscape coherence reduces regime responsiveness and slows systemic change [22].

At the regime level (provincial and industry), these structural constraints manifest as uneven institutional capacity, fragmented value chains, and persistent reliance on conventional construction practices. Provincial actors emerge as critical intermediaries responsible for translating national policy intent into operational frameworks, procurement systems, and skills development initiatives. Where this coordination is weak, organisation exhibit risk averse behaviour, limited investment in innovation and persistent reliance on established practices. Conversely, stronger provincial facilitation enables organisational learning, and partial alignment between policy intent and implementation. This reinforces the argument that regime level governance capacity is a decisive determinant of transition outcomes [23].

These constraints are most visibly expressed at the niche level (municipal and project), where implementation occurs. Municipal actors and project teams reported limited technical expertise, inconsistent regulatory enforcement, and weak performance monitoring systems. As a result, experimentation remains fragmented and localised, with limited opportunities for replication or scaling. Importantly, the findings indicate that these challenges are not driven by technological limitations, but by the absence of supportive institutional conditions. This supports prior research showing that innovation depends on enabling governance environments rather than isolated technological advances.

Crucially, the study identifies bidirectional feedback dynamics across levels. Weak implementation at municipal level reduces confidence in policy feasibility at provincial and national levels, risk aversion at policy inertia. This creates a self-reinforcing cycle in which. misalignment across governance tiers actively suppress transition momentum. These findings extend the MLP by demonstrating how governance fragmentation in developing contexts constrains the co-evolution of landscape, regime and niche dynamics.

Net Zero Building Acceleration Framework

In response, the Net-Zero Building Acceleration Framework (NZBAF) translates these cross-level dynamics into a governance aligned model for accelerating adoption. Rather than a static classification of barriers, the framework operationalises the multi-level perspective by mapping national (landscape), provincial (regime), and municipal (niche) roles within South Africa's governance system. This advances existing scholarship by explicitly linking transition dynamics to institutional responsibility, coordination capacity and implementation authority, addressing a key gap in net-zero literature.

The NZABF conceptualises adoption as a co-evolving process, where national policy coherence establishes enabling conditions, provincial actors mediate and operationalise these conditions, and municipal actors implement and generate learning through practice. By making these dependencies explicit, the framework identifies leverage points for intervention and demonstrates how misalignment across levels constraints adoption. In doing so, it reframes net-zero transitions from a question of technological readiness to one of institutional coordination and adaptive governance.

Governance aligned implementation pathway

Building on this, the framework supports a governance aligned implementation pathway that sequences interventions according to the most binding systemic constraints. The findings indicate that landscape level incoherence at the national level constitutes the primary bottleneck. Accordingly, the initial intervention lies in strengthening policy coherence through aligned standards, incentives and regulatory frameworks that provide clear direction and reduce uncertainty.

This intervention is not conceived as linear or top down, but must occur alongside parallel regime niche coupling, where provincial actors enable protected municipal experimentation through mechanisms such as pilot procurement frameworks and demonstration projects. These structured niches create conditions for innovation and learning despite incomplete system alignment.

Central to this pathway is a feedback mechanism through which milti-level implementation generates performance data and experiential knowledge that inform provincial coordination and iterative refinement of national policy. This transforms local experimentation into system wide learning. As alignment strengthens, the system becomes conducive to scaling, characterized by standardization, industry capacity development and financial market adaptation.

CONCLUSION

This study examined the landscape, regime, and niche level barriers and drivers shaping the adoption of NZC and NZW buildings in South Africa. Drawing on qualitative insights from 18 built-environment professionals, the findings reveal that net-zero transitions are constrained by interlocking governance, industry, and project level dynamics rather than isolated technical limitations.

The study makes three primary contributions. First, it provides an empirically grounded diagnosis of NZC and NZW barriers within a developing country context. Second, it advances sustainability transitions scholarship by operationalizing the multi-level perspective through a governance aligned framework spanning national, provincial, and municipal spheres. Third, it introduces the Net-Zero Building Acceleration Framework (NZBAF) as a context responsive model that explicates cross level interdependencies and identifies leverage points for accelerating net-zero transitions.

Practically, the findings underscore that achieving NZC and NZW at scale requires coordinated, sequenced interventions across governance levels. A governance aligned implementation pathway emerges in which policy coherence at national level serves as the primary entry point to reduce uncertainty and provide direction, while provincial actors enable protected municipal experimentation through coordinated mechanisms such as pilot procurement and demonstration projects. Crucially, implementation at the municipal level generates performance-based feedback that informs provincial coordination and iterative refinement of national policy, creating a continuous learning cycle across the system. As alignment strengthens, this enables the scaling of standards, industry capacity and financial mechanisms necessary for broader diffusion. Reframing net-zero adoption as a multi-level governance challenge, this study provides a robust analytical and practical foundation for accelerating sustainable built-environment transitions in South Africa and comparable emerging economies.

Future studies and recommendations

Future research should build on this study by incorporating broader and more stratified sampling within professional categories to capture intra-group diversity and strengthen empirical robustness. Quantitative or mixed method approaches could further test and validate the relationships and leverage points identified in the framework. In addition, longitudinal and comparative studies across different developing country context would be valuable in assessing the transferability and scalability of the framework. From a practical perspective, further work is needed to empirically evaluate the proposed implementation pathway, particularly the effectiveness of pilot interventions, feedback mechanisms and scaling strategies in developing context. Such research would contribute to refining the NZBAF from diagnostic and coordination tool into a more fully validated instrument for guiding net-zero transition in resource constrained environments.

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