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LETTER

The sufficiency gap: the demand-side deficit in German, Dutch, and Norwegian cement decarbonization roadmaps

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Abstract

Cement is an essential building material but producing it generates 7%–8% of global CO_2 emissions. Two thirds of these emissions are process-related and cannot be eliminated by switching to clean energy sources. Meeting the Paris agreement's call for 'highest possible mitigation ambition' requires faithful assessment of all mitigation options, including demand-side measures to reduce cement emissions. To assess how political actors define and justify their highest possible ambitions for the housing sector, we analyze cement decarbonization roadmaps in Germany, the Netherlands, and Norway: industrialized countries selected for their high floorspace per capita. We identified 30 decarbonization measures using qualitative document analysis. We coded the measures iteratively from roadmaps and literature and categorized them into a cement-specific mitigation hierarchy (avoid, reduce, reuse, substitute, minimize, 'Capture, Store and Recarbonate') that integrates supply-side decarbonization with demand-side sufficiency in housing. Our findings expose a persistent sufficiency gap: roadmaps prioritize incremental technical solutions and speculative carbon storage, while neglecting transformative measures that reduce overconsumption like separating spacious living units, building smaller or reducing housing overconsumption. This inflates cement demand, the need for carbon capture and storage as well as associated residual emissions. We conclude that current mitigation ambitions are not the highest possible but, instead, politically constructed versions that sideline demand-side sufficiency measures. Truly Paris-aligned pathways must first adopt a sectoral perspective to reduce cement emissions and then also integrate demand-side strategies through transdisciplinary collaboration, ensuring a faithful assessment of all mitigation options.

1. Introduction

Cement, a hydraulic binder in concrete, has unparalleled functional characteristics that make it an essential material in construction. Producing cement alone emits 7%–8% of all global anthropogenic CO_2 emissions (GCCA 2023). In total, this amounts to 2.4 billion tons of CO_2 annually with no reduction since 2015 (IEA 2024). 1.5 billion tons are process related emissions (Andrew 2018) that cannot be reduced through phasing out fossil energy carriers (IEA 2021). Moreover, global cement demand is projected to rise, driven by urbanization in the Global South as well as infrastructure renewal and expansion in higher income regions like Europe and North America (IEA 2021). This underlines the high urgency to decarbonize the sector.

Through the Paris Agreement, 195 countries and the European Union have committed to reaching carbon neutrality by 2050. Article 4.3 of the Paris agreement obliges parties to pursue the 'highest possible ambition' (UNFCCC 2015). This legal norm necessitates that countries reduce emissions as ambitiously as possible, which includes a faithful assessment of all mitigation options before declaring any emissions as residual emissions (Schönfeld and Rogelj 2025). Neumann (2025) argues that countries should adopt a sectoral approach to national determined contributions (NDCs) because only at this level can all mitigation options, including demand-side measures, be fully assessed. Analyses of residual emissions at the national level (Buck *et al* 2023, Smith *et al* 2024) and in companies' climate targets (Arendt 2024) reveal that mitigation levers are not systematically assessed before emissions are classified as residual. Many actors lack a definition for residual emissions. If they have one, they derive it inconsistently from subjective assessments of technical and economic feasibility, often with a narrow focus on supply-side measures. A critical limitation in most definitions of residual emissions and assessments of mitigation measures is the systematic neglect of demand-side/avoid measures (Lund *et al* 2023, Brad *et al* 2025).

Several studies have analyzed cement decarbonization and proposed measures such as energy efficiency, fuel switching, clinker substitution, and carbon capture and storage (CCS) (Barbhuiya *et al* 2024, Cavalett *et al* 2024, Kumar *et al* 2025, Ning and Unluer 2025). These studies often foreground supply-side measures, while some also consider circular strategies such as material reuse, building lifetime extension, or improved construction design (Olsson *et al* 2023, Van Oorschot *et al* 2023). At the same time, research on housing decarbonization shows that demand-side levers, particularly reducing material use, extending building lifetimes, and constraining floorspace growth, are also essential for meeting climate targets (Lorek and Spangenberg 2019, Wiese *et al* 2024). For example, research on Japan (Watari *et al* 2022) shows that cement emissions could fall by up to 80% if both supply- and demand-side measures (such as CCS, recarbonation, more intensive building use, longer lifetimes, and material-efficient design) are considered. Such sufficiency measures must complement efficiency gains and renewable energy in building decarbonization, because 'global growth in floor area is outpacing the existing efforts to decarbonise the sector' (IEA, IRENA, and UN Climate Change High-Level Champions 2023). This reflects a classical rebound effect: pure efficiency gains rarely lead to overall reductions (Brockway *et al* 2021). Material flow and climate models further substantiate this, demonstrating the significant emission reduction potential from limiting floorspace increase (Pauliuk *et al* 2021, Edelenbosch *et al* 2024, Napiontek *et al* 2025). Building on these insights, this article examines whether such established mitigation options are reflected in cement decarbonization roadmaps.

We focus on the housing sector because, although cement demand is also driven by infrastructure and non-residential buildings, housing accounts for around 30% of global cement demand and indirectly drives infrastructure expansion (Verein Deutscher Zementwerke e.V 2022). In high-income countries, under-occupation often exceeds overcrowding (Huebner and Shipworth 2017, Gough *et al* 2024, Horn *et al* 2025). This implies that demand could be met by optimizing existing housing stock rather than expansion. At the same time, market-driven housing provision often prioritizes profitability and status consumption over need, reinforcing this mismatch (Nelson *et al* 2019, Savini and Bossuyt 2022, Zu Ermgassen *et al* 2022, Holm *et al* 2023, Horn *et al* 2025). Housing therefore provides a particularly suitable setting in which to assess whether cement decarbonization roadmaps engage with demand-side sufficiency.

We therefore analyze Germany, the Netherlands, and Norway, high-income and high-floorspace economies in which projected cement demand, housing expansion plans, and existing housing sufficiency potential are in tension. Against this background, the paper assesses the ambition of national cement decarbonization roadmaps and asks whether they adequately account for the full range of available mitigation measures, including demand-side sufficiency levers. Further information on the cases, their cement demand, and available floorspace is provided in supplementary material section 1

2. Method

To assess the comprehensiveness of cement decarbonization roadmaps in identifying mitigation measures, we first selected key roadmap documents for analysis. Decarbonization roadmaps are strategic frameworks that outline actions to reduce greenhouse gas emissions. As instruments of futuring, they project how technology and society should develop according to a strategic plan (Carvalho *et al* 2013). To obtain relevant roadmaps to decarbonize cement, the following systematic strategy was pursued: we started with roadmaps that we knew from previous experience. We conducted a web-based search using the Google search engine to identify more roadmaps (using the string 'country name' + 'net zero' OR 'carbon neutral' both with and without 'cement' in both native languages and English) and continued with snowballing until the point of saturation. The searches were conducted up until the end of July 2025 for Germany and the Netherlands, and for Norway until end of October 2025.

The roadmaps had to meet the following inclusion criteria. They should be authored or funded by a political entity, such as a governmental authority, industry body, NGO, think tank, public private partnership or civil society organization. Additionally, they must focus on economy-wide or cement-specific decarbonization pathways that aim to reach carbon neutrality or net-zero emissions, where the required measures are derived by working backward from this target. Only decarbonization roadmaps from overarching or cement-specific industry associations were considered; those from individual companies, regional states, cities, or other more specific sectors are excluded. This also applies to roadmaps that are only focused on energy, the built environment, circularity or energy efficiency. The long-term low greenhouse gas emission development strategies which countries submit to the UNFCCC were excluded, because none of them contained a detailed roadmap of cement decarbonization (Kingdom of Norway 2020, Kingdom of the Netherlands 2020, Federal Republic of Germany 2022); the same applies to the countries' NDCs (European Commission 2025, Kingdom of Norway 2025). The search resulted in 15 roadmaps for Germany and eight for the Netherlands and Norway, respectively. All roadmaps are provided in supplementary materials section 4.

To evaluate the decarbonization roadmaps, this study develops an integrated mitigation hierarchy framework for structuring and identifying mitigation measures in decarbonization roadmaps. While the mitigation hierarchy is broadly applicable, we apply it specifically to the cement sector. We adopted the mitigation-hierarchy framework, as it is commonly used in decarbonization efforts and in broader debates on net-zero and carbon neutrality. Non-adherence to the mitigation hierarchy is a major reason for the limited success of net zero in climate policy (McLaren and Carver 2023).

The mitigation-hierarchy framework goes beyond cost-optimization by sequencing mitigation measures to prioritize avoidance over end-of-pipe options like CCS: avoiding construction (A), reducing demand (e.g. extending building lifetimes) (B), optimizing use by aligning buildings with needs (C), lowering material emissions through substitution and reuse (D) and cleaner production (E), and finally managing residual CO_2 via capture, storage, and recarbonation (F). The integrated mitigation hierarchy for cement is shown alongside the traditional mitigation hierarchy in figure 1.

The structure and content of this integrated mitigation hierarchy are developed in the following sequence:

1. Coding decarbonization documents and measures: roadmaps from Germany, the Netherlands, and Norway were systematically coded in Atlas.ti using the derived mitigation hierarchy. This process identified proposed decarbonization measures, which were supplemented with additional measures drawn from housing sufficiency hierarchies and literature (Bierwirth and Thomas 2019a, 2019b, Fuchs et al 2021, Zimmermann et al 2023). All measures and hierarchy stages are detailed in supplementary material section 3.
2. Categorizing within the hierarchy: each identified measure is categorized into the most appropriate step of the mitigation hierarchy.
3. Framework refinement: the coding categorizations were regularly discussed among the involved researchers to increase intercoder reliability. While alternative categorizations were possible, this framework sufficiently captures whether the mitigation hierarchy's measures are represented.

The primary objective was to develop an integrated mitigation hierarchy framework to assess the spectrum of decarbonization measures in current decarbonization roadmaps for cement.

In the mitigation hierarchy, CCS occupies a special role. The International Energy Agency's Net Zero Emissions pathway projects that 1.355 Gt of CO_2 from cement production will be captured and stored annually by 2050 (IEA 2021), compared with only about 50 Mt of global operational CCS capacity across all sectors today (IEA 2025). CCS does not avoid generation of CO_2 but manages CO_2 as waste. Large-scale deployment of CCS infrastructure remains highly uncertain, as many projects fail, underperform, or are never implemented (Abdulla et al 2021, Kazlou et al 2024). Additionally, CCS introduces long-term storage risks. Given these differences, CCS is treated as a last resort in the derived mitigation hierarchy in this paper, since it manages rather than avoids generation of CO_2. Where other options remain unused, CCS may delay structural reductions and contribute to mitigation deterrence. The stance in this paper contrasts sharply with others that consider CCS to be regular mitigation. For instance, Dufour-Décieux et al (2025) argue that waste streams suitable for CCS are not 'hard to abate,' effectively treating them as abated. This position is aligned with the cement sector guidance of the Science Based Targets Initiative (2022), which only defines emissions as 'residual' that cannot be captured and stored.

3. Results

The derived mitigation hierarchy for cement decarbonization and its demand in housing spans a continuum from transformative demand-side reductions to supply-side technological solutions. At its most impactful base, Stage A (Sufficiency & adaptive reuse) focuses on avoiding the need for new material and residential buildings by reducing per-capita floor space,

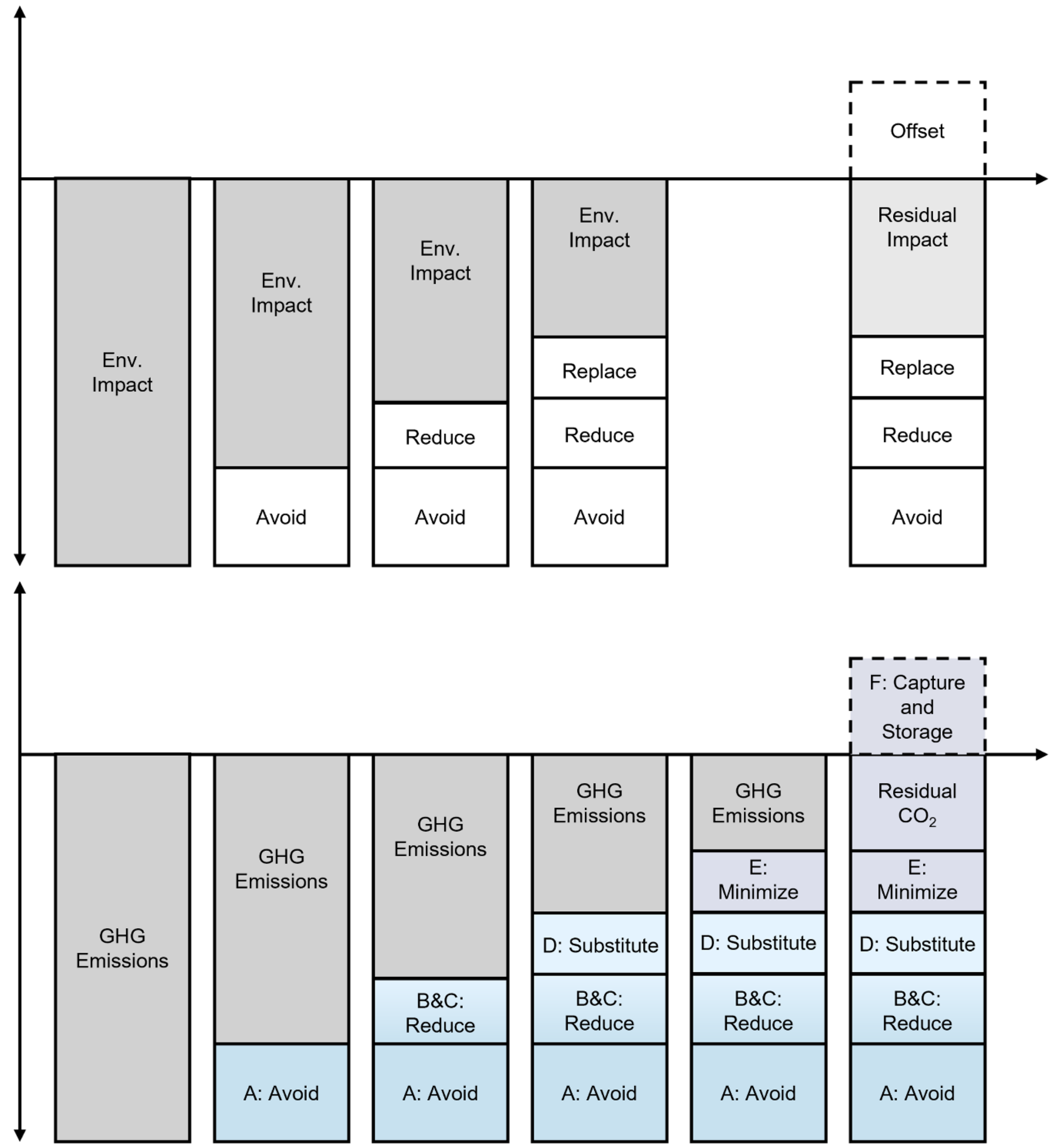

Figure 1. Normal mitigation hierarchy (above) and adapted cement mitigation hierarchy (below) (own illustration).

through house-sharing, repurposing vacant buildings, and subdividing existing large housing units. The next stage is Stage B (extend lifetimes of buildings), which seeks to extend the lifetime and use of existing buildings, preventing demolition and the subsequent need for new buildings with new cement.

This is followed by Stage C (adequately sized construction), which addresses how we build if new buildings are necessary to satisfy housing needs. Thus, dwellings for smaller household sizes and multi-family homes are given priority to satisfy need with minimal resource input. Stage D (substitution of new building parts with reused or alternative materials) then tackles the material composition itself, replacing high-emission cement with lower-carbon alternatives like reused components, alternative materials or concrete with less cement content.

On the supply side, Stage E (minimize) improves conventional production through fuel substitution, energy efficiency, and reducing the clinker content in cement. Finally, Stage F (carbon capture & recarbonation) serves as the end-of-pipe technological solution, capturing and storing emissions after CO_2 is produced.

We next analyze how this theoretical hierarchy translates into national roadmaps, by assessing the measures within 15 German roadmaps and 8 from the Netherlands and Norway, respectively. Figure 2 shows the relative frequency of the measures for all three countries. The measures in figure 2 are classified, described and numbered in the supplementary material section 3.

Our analysis reveals a consistent pattern across all national roadmaps: a clear preference for supply-side

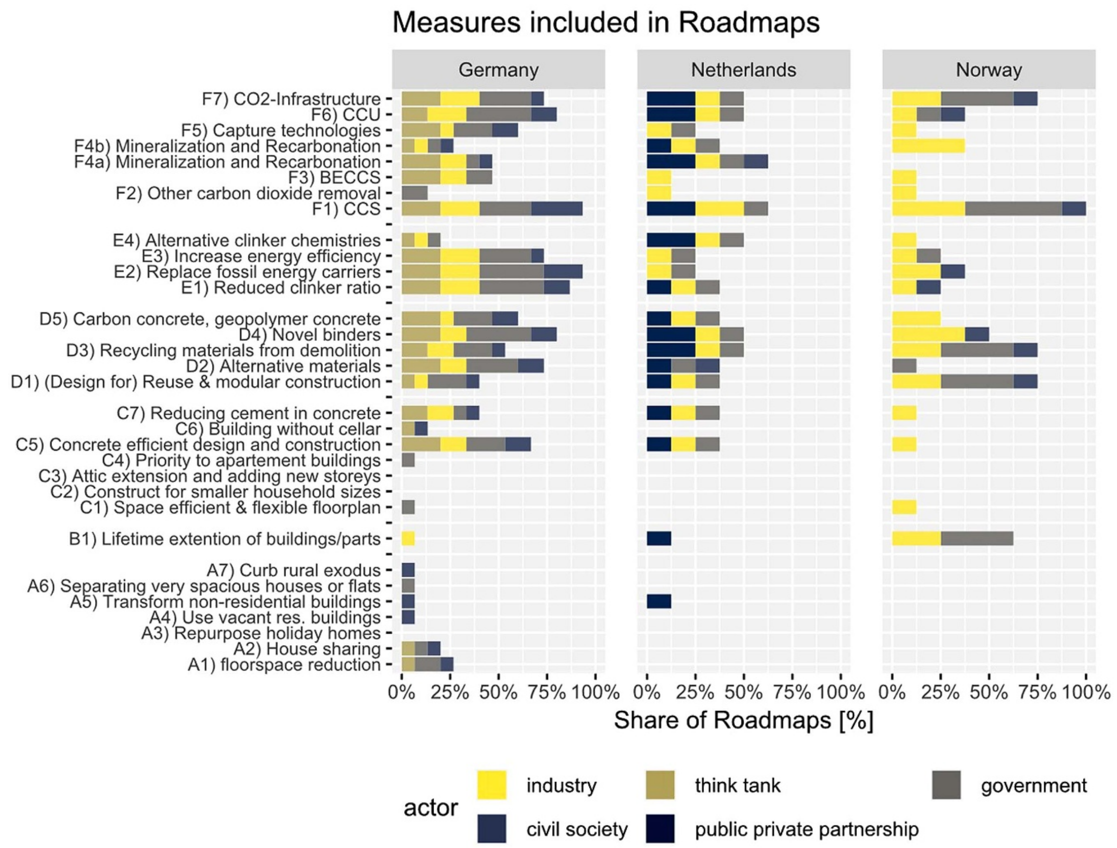

Figure 2. Frequency of mitigation measures in national cement decarbonization roadmaps (Germany: n = 15; Netherlands: n = 8; Norway: n = 8). The frequency from A–F is inverted to reflect the predominant focus on supply-side measures (F&E) over demand-side measures (A–C). A higher resolution version of the figure per country is provided in the supplementary materials section 5. (own illustration).

technological measures (a stronger emphasis of measures in E and F) over demand-side reduction measures (A–C). We interpret this as an inverted mitigation hierarchy, which is most visible in the universal prominence of CCS (F1): the most frequently mentioned measure in all analyzed countries. However, there is also a predominance of measures from stages F, E and D compared to stages C, B and A.

Interestingly, this tendency is observable in government and industry roadmaps alike. Civil society pathways, particularly in Germany, mention sufficiency measures slightly more often, but ultimately still conform to the same overarching supply-centric framework. Technological details of CCS, such as a CO_2 infrastructure (F7), specific capture technologies (F5) and CCU (F6) are mentioned relatively often in all roadmaps. The measures, building smaller units (C2), prioritizing attic extension and adding stories over new construction (C3) or repurposing holiday homes (A3) originating for the literature of housing sufficiency, are neglected by all countries in all roadmaps.

Beyond this common reliance on CCS and neglect of sufficiency measures, the countries show some variation. German roadmaps focus on process changes like replacing fossil fuels for burning clinker (E2), while Dutch strategies frequently mention enhanced recarbonation (F4a). Norwegian pathways highlight circular economy measures (D3 and D1) and extending the lifetime of buildings (B1) frequently. In Germany most sufficiency measures occur at least once in civil society roadmaps, yet they lack systematic quantification of potential savings (Wuppertal Institut 2020). CCS is both the most frequently mentioned measure and the quantitatively most important lever in most pathways, as discussed in the following.

For German pathways, only the earliest roadmap from 2019 excludes CCS, all the roadmaps afterwards rely on it. The RESCUE study (Purr *et al* 2019) stands alone in excluding CCS and reducing cement emissions from 20 million tons of CO_2-e to 5 million tons of CO_2-e and to balance these remaining emissions out with natural sinks. Later German studies, however, uniformly rely heavily on CCS and assume that CO_2 production will less than half in the next 25 years, with estimates ranging from 10 Mt CO_2-e (Boston Consulting Group 2021, VDZ 2021) to 12.6–15.5 Mt CO_2-e (Prognos, Öko-Institut, and Wuppertal-Institut 2021, Büro für Technikfolgen-Abschätzung beim Deutschen Bundestag (TAB) 2024). Notably, the Boston Consulting Group's framing of CCS as the 'most important lever' again inverts the mitigation hierarchy's principle, positioning carbon capture as a first rather than last resort. The high reliance on CCS could have been facilitated by industry influence, particularly from the roadmap published by the VDZ (2021).

Many Dutch roadmaps did not mention cement specifically, potentially because they are scope 3 emissions (Kalavasta and Delft 2025). The Dutch McKinsey study briefly identifies cement as a source of hard-to-abate emissions requiring CCS but offers no detailed decarbonization pathway for cement (McKinsey Sustainability 2023). Moreover, they mention hard-to-abate emissions from burning clinker, which does not occur in the Netherlands. The PBL study that covered cement notes that 95% of emissions are upstream emissions that happen abroad, yet it does not quantify upstream emissions tied to Dutch cement consumption (Xavier and Oliveira 2021). The Betonakkoord (concrete agreement) estimates a potential of reducing emissions with CCS of up to 2.3 million tons yr^{-1} by 2050 (van Gent 2021). Other roadmaps lack a quantification of CCS contribution up until 2050.

For Norway, CCS is mentioned in all the pathways without exception. In the context of the government co-financed Longship project for CCS at the Brevik plant (the first cement plant globally that implements CCS) (Norwegian Ministry of Petroleum and Energy 2020), it is clear that Norway is putting high emphasis on this practice. Moreover, CCS is one of the prime future business opportunities for Norway, because of its large storage capacity. A Norwegian McKinsey report claims that CCS is economically viable for 43% of Norway's industrial emissions (Lund *et al* 2022). Norway is also the only country for which all category A levers are completely absent. The only mentioning of a possible higher-level measure is the sharing or renting out of holiday homes but without consideration to transform them to permanent residential buildings (Klimamelding 2035—på vei mot lavutslippssamfunnet 2025), which is why we did not categorize it as A3. The pathways differ in their prediction of the quantity of CCS, but all pathways count on it as a significant measure towards carbon-neutrality. When estimated quantities for cement's future CO_2 emissions are provided, they range from 0.8 to 1 million tons (Hermstad 2025, Skanke *et al* 2023), which equals to nearly no reduction of cement emissions from today's level.

While each country navigates its own industrial context, their roadmaps converge both qualitatively (in their strategic orientation) and quantitatively (in their scale of deployment) on technological measures, particularly CCS. To support this finding, we further evaluated the extent to which the roadmaps quantified the magnitude of CCS in their target year (supplementary material tables 3–5) figure 3 visualizes the derived integrated supply and demand-side mitigation hierarchy using an iceberg metaphor to symbolize the hierarchies' inversion.

The reversed frequency trend from A to F is evident in the hierarchy's flip: CCS, the first technology, occupies the tip of the ice-mountain (F) and appears in nearly all pathways alongside the minimize (E) stage. In contrast, measures with the greatest emissions-reduction potential (A–C) are rarely considered. In our iceberg metaphor, they form the largest portion of the iceberg hidden beneath the surface, whereas category D occupies an intermediate position at the waterline. The inverted frequency highlights a critical sufficiency gap: while technical solutions dominate roadmaps, systemic demand-side measures that extend beyond individual consumer choices remain marginalized. The metaphor reveals the hierarchy's sequence and inversion but not the quantitative weight of each section.

4. Discussion & outlook

This paper exposes a sufficiency gap in the cement decarbonization roadmaps of Germany, the Netherlands, and Norway. We structure the discussion as follows: (1) discussing the supply-side bias in cement roadmaps for housing and its implications for the highest possible ambitions and the structural causes of the bias; (2) reviewing historical precedents, such as 1970s Dutch housing policy, that successfully met housing needs without excessive construction; and (3) outlining conditions for more ambitious future decarbonization such as housing decommodification.

The analyzed cement roadmaps rely overwhelmingly on technological solutions. Excluding local and corporate roadmaps, and not explicitly searching for roadmaps focused on the built environment, may lead to the omission of emerging or context-specific mitigation measures. This choice may also bias the analysis toward national-level priorities and more standardized approaches, potentially underrepresenting experimental or sufficiency-oriented strategies developed at the city scale. However, the selected sample still captures key actors and their priorities. Based on the analysis, a clear pattern emerges: roadmaps systematically avoid questioning the paradigm of cement demand and associated consumption patterns, such as per-capita floorspace, thereby revealing a 'sufficiency gap' in the omission of demand-reduction measures. The concept of a 'sufficiency gap' builds on the literature on policy and implementation gaps, such as the energy efficiency gap (Jaffe and Stavins 1994). However, it differs in that it arises from the omission of demand-side and sufficiency-oriented measures at the planning stage, rather than from the under deployment of known, cost-effective options. Further research

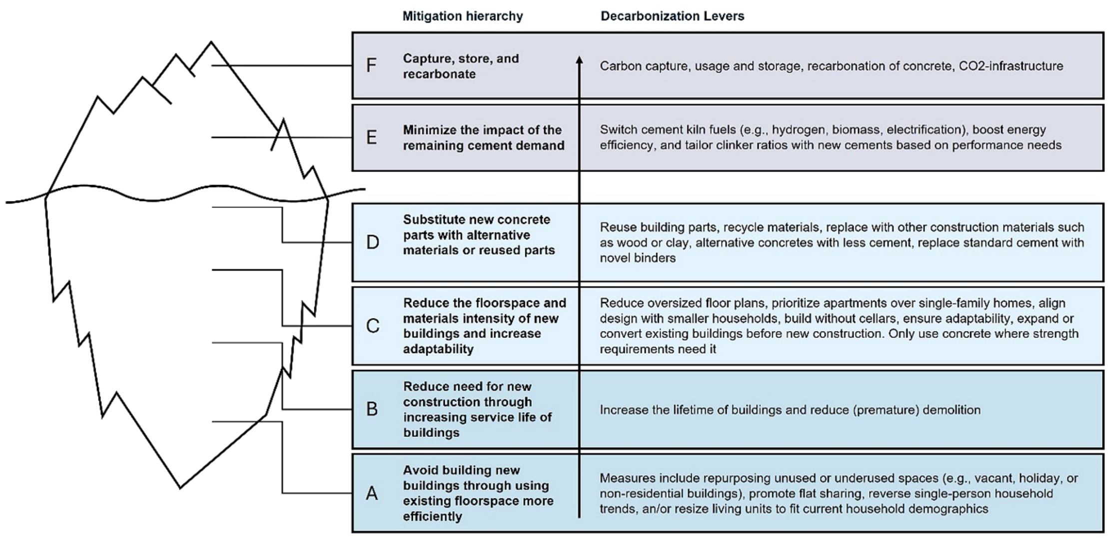

Figure 3. Integrated supply and demand side mitigation hierarchy, that is symbolized by an iceberg metaphor (own illustration).

could quantify this gap and assess integrated supply- and demand-side strategies for cement use beyond residential construction. Doing so, however, would require a substantially expanded analytical scope and systematic engagement with additional literature on sufficiency in infrastructure and non-residential buildings.

The identified 'sufficiency gap' raises doubts about whether the analyzed roadmaps meet the Paris Agreement's requirement of 'highest possible ambition', as demand-side sufficiency measures are systematically neglected despite available scientific literature. This norm is operationalized through NDCs, yet while the EU and Norwegian NDCs reference CCS for industrial emissions, their lack of sector-specific detail raises concerns about whether the full range of mitigation options is considered for cement. This highlights the need for more explicit sectoral pathways within NDCs, including transparent assumptions on future demand and production levels (Neumann 2025). Both adopting a mitigation hierarchy and treating all mitigation options as equivalent constitute normative choices. However, prioritizing measures that avoid emissions or reduce risks, for example minimizing reliance on CCS storage, aligns more closely with the principle of 'highest possible ambition' and supports a more faithful assessment of mitigation potential, as it foregrounds the relative effectiveness and uncertainties of available options.

The 'sufficiency gap' is a structural outcome of growth dependencies—conditions where wellbeing is compromised without growth—which act as a major barrier to a post-growth transition (Stratford 2020, Walker et al 2021). In housing, these manifest as political-economic lock-ins: homeowners rely on continuous price appreciation for financial stability, and sufficiency policies put homeowners in a 'financially precarious position' (Heslop and Ormerod 2020, Ermgassen et al 2022). In some jurisdictions, municipalities compete for high income residents to expand their tax base, with spacious housing construction as a primary tool to attract them (Bierwirth and Thomas 2019b). Additionally, municipalities might rely on urban development and new growth to generate income because urban development and land revenue are preconditions for public investment (Savini 2021). Thus, the political economy of housing reinforces cement demand, sidelining demand-side measures in decarbonization roadmaps.

Historical precedents can demonstrate that acting further up the mitigation hierarchy can be feasible to fulfill housing needs. We illustrate this through the late-modernist epoch of 1970s Dutch housing policy, during which economic and demographic growth seemed to come to an end (Verlaan 2015). In 1975, the progressive Den Uyl administration published a memorandum on the housing needs of single and two-person households. It proposed building new housing complexes with smaller floorplans and shared facilities, to subdivide larger homes into separate housing units, and to make vacant commercial and government buildings available for residential use, which all required simple construction and low rents. By 1985, 77 000 housing units for singles and childless couples were built, mostly in inner urban areas. Many of these units were realized through decommodification: private landlords were bought out by local governments and their properties converted to public housing, while squatted private properties were legalized. Partially because of these efforts, by the 1990s nearly half of all Dutch housing was publicly owned, giving authorities major control over the housing system. Yet around the same time, neoliberal reform began to reshape the same system, promoting homeownership and driving the privatization of social housing (Woltring 2024).

The Dutch policies reveal pathways rarely debated in contemporary climate roadmaps. By capping housing as speculative assets, it enabled moving past a system that prioritizes floor-space growth governed by private actors that want to maximize profits. Rising living costs have reignited grassroots momentum for the 're-municipalization' of housing, most notably in Berlin (Berfelde and Möller 2023). Such political campaigns explicitly link social justice with ecological sustainability (Arendt *et al* 2023) advocating for the expropriation of large landlords to establish democratic, needs-based governance. Other countries can serve as examples too, where public ownership allows for needs-based allocation. In Switzerland, policies against under-occupancy in public housing are perceived as fair because they facilitate access to larger homes for those that need more space (Lage 2025).

Public land ownership alone does not guarantee sustainability, but it enables a crucial sufficiency lever: directing housing development toward social need, not market demand. As the Dutch example showed, it allows for the intensive and equitable use of existing stock and building for those with the highest need. This illustrates how decommodifying housing can promote sufficiency through public planning, particularly in contexts with high floorspace per person. Under market delivery, cement flows toward profit and space for the wealthy (Savini *et al* 2026). A planning approach that prioritizes housing as a social good, rather than a market commodity, could focus on measures that meet housing need through existing stock (A1, A2, A6) and building adequately sized for smaller households (C2), closing the sufficiency gap left by current roadmaps. When markets lock in overconsumption, changing who owns and controls housing becomes essential to enact sufficiency. Therefore, the systematic inversion of the mitigation hierarchy in current roadmaps is not merely unjustified, it is a failure to address the core political economy of cement demand and urban expansion.

5. Conclusion

A critical sufficiency gap runs through the cement decarbonization roadmaps for housing in Germany, the Netherlands, and Norway. This represents a systematic inversion of the mitigation hierarchy, which prioritizes speculative supply-side technologies like CCS over demand avoidance in housing. The sufficiency gap represents a high-stakes gamble, as CCS introduces systemic risk compared to other mitigation options. Consequently, these roadmaps may achieve net-zero in models while leaving real-world outcomes deeply uncertain. This inversion reflects a profound failure of political and economic imagination: it is easier to envision pumping megatons of CO_2 underground than to limit excessive construction, challenge ownership structures, or utilize existing housing stock more equitably. A truly ambitious climate policy, as required under the Paris Agreement, must reverse this logic: it should begin with sector-specific decarbonization pathways that incorporate the full range of mitigation options and center on the verifiable, near-term benefits of demand-side action alongside supply-side strategies. Decommodifying housing represents a little discussed enabler of sufficiency, creating the political and economic conditions to implement demand-side measures effectively.

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Data availability statement

All data that support the findings of this study are included within the article (and any supplementary files).

Supplementary Material available at: https://doi.org/10.1088/1748-9326/ae692f/data1.

AI-Statement

The authors used DeepSeek and ChatGPT to modify the writing of this paper.

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