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Prioritize energy sufficiency to decarbonize our buildings

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Standfirst: To decarbonize our buildings, we need human behavioral change. This arises from our needs, lifestyle energy choices, and interactions with buildings, and is an underexploited, yet essential demand-side opportunity for rapid and sustainable decarbonization. We propose a sufficiency-oriented approach that fosters equitable building decarbonization, while maintaining planetary boundaries.

The current climate crisis requires profound transformations in the global energy system involving decarbonization and low-emission pathways in all the major energy-consuming sectors. We must focus on buildings (and the construction sector) when responding to the climate crisis, as they contribute to 36% of global final energy consumption and 37% of energy-related carbon emissions.[1] Technological transformations such as adoption of energy-efficient technologies, retrofitting to meet higher standard requirements, and deployment of clean energy infrastructure have been at the forefront of building decarbonization since the past few decades. However, a relatively slow adoption of renewables, high initial costs of electrification, and associated justice issues, such as low-income households having limited access to renewable energy benefits, have hindered the current energy transition. Global energy inequity is also unacceptably high: the annual energy consumption of a single refrigerator in the U.S. is three times as high as the entire annual energy consumption of an individual in several African countries.

To overcome these challenges, we must rethink the way people use energy, to better understand who needs the greatest support and in what way to reduce structural inequities. We call for stakeholders, especially policymakers, to integrate the human dimension of energy use in building decarbonization strategies, for an equitable and just energy transition.

The case for energy sufficiency

Energy sufficiency is grounded in the principle that "small is beautiful,"[2] and to achieve this, we need to moderate consumption through behavioral change (see Box 1 for definition and discussion). The aim of energy sufficiency is for humans to limit their energy needs within the planetary budget. To characterize sufficiency thresholds, i.e., the levels of energy needed for decent living, we must consider human needs, energy services, urban structures, social norms, and consumption habits. However, socioeconomic status is not considered when determining sufficiency thresholds. Moreover, achieving energy sufficiency can also yield co-benefits of reducing inequity, poverty, and environmental impact, and ensures decent living standards (DLS) for all[7].

Box 1 Energy conservation, efficiency, and sufficiency

Energy conservation: Using less energy to reduce the level of energy demand.

Energy efficiency: Reducing the amount of energy required to provide the desired level of energy demand.

Energy sufficiency: Avoiding superfluous consumption to limit energy demand within planetary boundaries.

Energy sufficiency is analogous to energy conservation in the sense that both are behavioral approaches for curtailing energy use. However, energy sufficiency respects the planetary boundaries and considers equity and well-being for optimal reduction of energy consumption levels, while energy conservation focuses solely on the quantity of energy consumption. In essence, energy conservation can be viewed as a subset of sufficiency. In comparison with energy conservation, energy efficiency aims at reducing the amount of energy input required to deliver a certain level of energy service; however, energy sufficiency emphasizes reducing the need for energy service by limiting consumption within the environmental boundaries. For instance, when washing and drying clothes we may follow energy conservation by operating on full load cycles. An approach based on energy efficiency would be to use a low-energy high-efficiency washer and tumble dryer. An approach based on energy sufficiency would be to cold wash the clothes, followed by line drying. However, sufficiency and efficiency approaches must not be viewed as contrasting, but rather, as complementary levers to realize the full potential of reducing energy consumption.

Energy sufficiency within buildings can be defined as the absolute reduction in energy demand by avoiding superfluous consumption through behavioral or lifestyle changes. The sixth IPCC report estimates that, by 2050, at least 10% of the baseline GHG emissions in buildings could be reduced by sufficiency measures, but the analysis is limited to structural changes of reducing floor space[3]. However, energy-sufficient behaviors within buildings could also include other structural changes, (such as prioritizing intensified multifamily housing over single-family homes) or sustainable behavioral choices in daily practices and routines (such as adopting natural ventilation or fans over mechanical cooling systems, or a shift in laundry practices from machine drying to line drying). There is a clear need for consumption reduction through voluntary actions or policy-induced behavior change, and this is also acknowledged by the report[4].

It is important to acknowledge that these structural changes or behavioral choices do not imply sacrificing DLS for all, especially seeing how energy-poor populations likely already engage in a lot of low-energy behaviors. Rather, they should be aimed at 'living well on less'—especially if they include co-benefits such as greater social cohesion or community living, and reduced energy hardship.

Currently, significantly high shares of the population in the Global South (particularly in sub-Saharan African and South Asian countries), are living below DLS with regard to building-related energy needs[5]. In the coming years, we expect to see the building energy and material demand surge in the Global South, particularly India, to accommodate the rising population growth, urbanization, and air-conditioner penetration necessitated by global warming. It is highly likely that we will also see a corresponding increase in lack of energy access in these regions.

Within the Global North, there exist no such DLS gaps. Instead, the scientific evidence has been unequivocal that the Global North consumes four times the estimated ideal limits of energy use per capita needed for human well-being for a decent life[6]. We support calls for energy redistribution among the high-emitting population groups such as high-income consumers of the Global North and the low-emitting population groups such as the underserved energy users of the Global South to reduce inequities in energy access and close the existing DLS gaps [5,6]. We must pay attention to how lifestyle changes and subsequent behavioral choices (both on the individual and collective level) impact building energy and material (hereafter termed as 'energy') demand.

We must seize this opportunity to reduce energy demand in buildings through a sufficiency-oriented decarbonization approach that entails energy demand being driven primarily by needs rather than a desire for affluence. In addition, sufficiency levels need to be defined based on the context, such as lifestyle practices, social norms, consumption patterns, existing infrastructure, and climate, and must be reassessed over time.

Sufficiency to decarbonize buildings

Prior research shows the potential of sufficiency-oriented behavioral measures in buildings. However, little is known about the connection of sufficiency measures (such as caps on dwelling sizes or optimizing appliance sizes to suit user needs) to the broader building decarbonization strategy. Figure 1 presents a schematic illustrating the role of sufficiency for building decarbonization and its linkages with human behavior. We introduce energy sufficiency as the first pillar and the core to decarbonize buildings that involves limiting energy use within the planetary boundaries. Sufficiency measures can also support the other three pillars: efficiency, flexibility, and resiliency. Sufficiency itself is the use of behavioral change as a tool for reducing energy demand. This can be facilitated by technology and policy. An example of building energy sufficiency measure is a U.S. utility company alerting customers for setting cooling setpoints above 25.5°C during a record week-long heatwave event in 2022 to manage rising energy demand. Similarly in Spain the government banned a cooling setpoint below 27°C to tackle the European energy crisis.

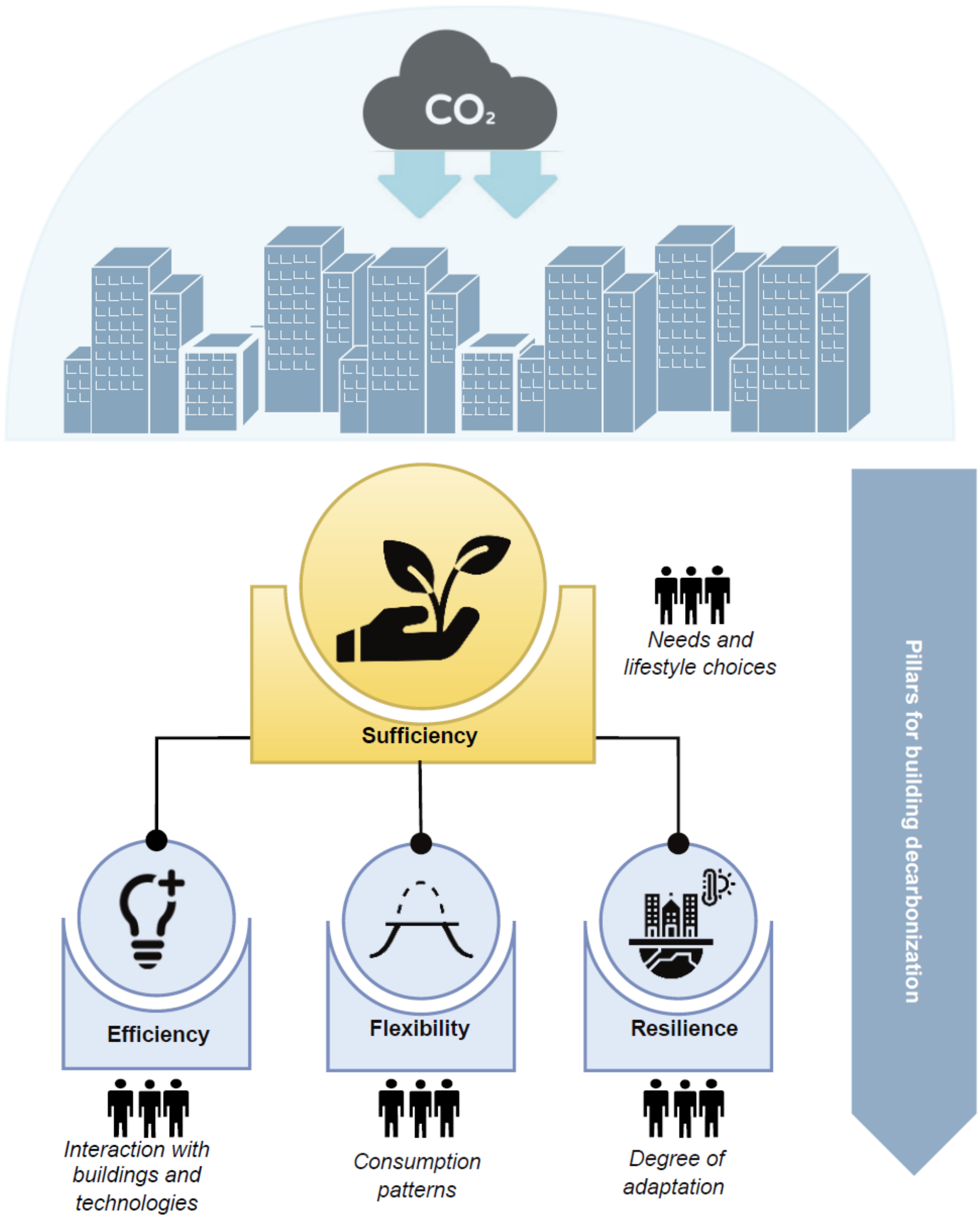

Figure 1: A schematic illustrating the importance of energy sufficiency for building decarbonization and its linkages with human behavior *(Icons reproduced/adapted from The Noun Project)*

The above examples show how sufficiency policies can be implemented reactively; however, we call on governments to integrate sufficiency within the decarbonization approach from the start to realize its full potential (including social acceptance), rather than implementing it as a forced measure in response to certain circumstances such as extreme weather events. Such measures should consider the needs and well-being of all occupants to determine the sufficiency–excess threshold. We should also assess sufficiency policies in terms of their impact on human health and wellbeing, not just energy or carbon reduction - unless there is a danger of blackouts or grid collapses.

Another crucial aspect that relates sufficiency and the other three pillars of building decarbonization is the human dimension of energy use. Human aspects such as habitual behaviors (which form the majority of our energy-use) and lifestyle choices dictate the efficacy of sufficiency actions. Technologies such as decentralized space heating and cooling systems or variable power appliances should be available to building users, to enable sufficiency-oriented lifestyle and behavioral choices. We also support the implementation of policy instruments such as financial incentives for building retrofits to encourage adoption of sufficiency measures. In summary, the sufficiency approach, which involves meaningful changes in human energy use behavior, should be at the core of building decarbonization.

New Directions

The building decarbonization agenda must prioritize energy-sufficient behavior that enables humans to thrive within ecological limits. To achieve this goal, we need to build an interdisciplinary and collaborative community of social scientists, economists, ethicists, building scientists, building practitioners, engineers, utility industry program managers, politicians and policymakers, as well as frontline and community providers and other trusted middle actors (e.g., contractors and trades services). Table 1 presents key recommendations for different stakeholders to implement energy-sufficient behavior. To achieve this vision, we recommend, the following priority areas for action: quantify energy sufficiency, identify barriers and enablers of energy sufficient behavioural change, model sectoral interdependencies, and develop effective instruments for achieving behavioural change.

Table 1: Key recommendations for the community to foster building energy sufficiency.

Stakeholder	Action Items
Government and Policy Makers	• Integrate voluntary sufficiency initiatives into the national decarbonization agendas (e.g. EU 'Save Energy' Directive; India's Mission LiFE initiative) • Revise building codes (e.g. San Francisco city building code's reduction in minimum living space) and appliance standards (e.g. the U.S. EPA Energy STAR or German label "Blauer Engel")

	• Restructure tax policies (e.g. progressive tax on rent collected by landlords owning more than two properties) and split incentives between landlords and tenants (e.g. New Zealand government's Warmer Kiwi Homes program).
Building and Energy Scientists	• Integrating the energy and carbon impacts of sufficiency measures (such as implementing decentralized HVAC systems, adopting low-energy laundry practices) into national decarbonization assessment modeling tools such as Scout or China 2050 Demand Resources Energy Analysis Model. • Model impacts of sufficiency measures such as heating, cooling, reduction in appliance usage on other sectors including transportation, food and manufacturing.
Social Scientists	• Co-design behavioral change programs for low-carbon lifestyles, e.g., drawing on evidence from historical sumptuary laws or current luxury taxes in Europe, Canada or U. S. such as California's Mansion tax. • Harness social contagion for instance by framing new narratives for climate mitigation in response to extreme weather events. • Build relationships with trusted frontline providers, such as service providers (e.g., tradespeople, insulation installers, social support services) or community organizations (e.g. churches, food banks, charity stores).
Economists	• Develop alternative metrics for economic progress (e.g. New Zealand's Wellbeing measures). • Assess the impacts of sufficiency measures on the wider economy (e.g., reduced air travel or car-based transport) • Formulate resiliency plans in response to the climate crisis.

Non-profit and community-based organizations	• Promote energy-sufficient behaviors and energy literacy by harnessing behavior contagion and informational instruments such as education, training, and community-led campaigns. (e.g. the European project - Fundamental Decarbonisation Through Sufficiency by Lifestyle Changes). • Partner with industry, government and science organizations to break down siloed thinking via engaging in true co-design (e.g. European Futures for Energy Efficiency).
Urban Planners, Architects, Designers	• Implement participatory urban planning policies to promote energy sufficiency (the importance of a participatory approach can be seen in the failure of Portland (U.S.) city's 20-minute Neighborhoods initiative to reduce car use). • Design flexible spaces and create co-living communities (e.g., micro apartments developed in Asia, Europe, and North America). • Consider ecosystem services such as tree shading or urban greening to reduce cooling loads. • Implement rainwater harvesting to reduce outdoor watering demands. • Create community gardens, and riparian plantings or wetlands that can be communally enjoyed instead of individualistic consumption.
Technologists (Appliance manufacturers, material scientists, air-conditioning product manufacturers, user experience developers).	• Engage with other disciplines such as social scientists in co-design from the beginning. • Develop novel solutions such as appliances with higher quality and longer lifetimes, variable power options and improved serviceability (e.g., provide half-load settings for dishwasher and washing machines).

	• Implementing decentralize building systems (e.g. modular design of HVAC systems, portable air conditioners, heating and cooling chair). • Use new, energy efficient materials (e.g. adaptive building envelope). • Focus on user-centered co-design based on qualitative insights and prototyping (e.g. the international collegiate competition Solar Decathlon building challenge).

Firstly, we need to develop robust indicators of energy sufficiency to quantify the impact of sufficiency measures on building energy use and carbon emissions. Examples of existing energy sufficiency indicators include appliance lifetime performance scores, or energy use per capita, as these truly reflect the sufficiency potential. Currently, most well-established modeling frameworks developed for assessing building decarbonization potential are primarily designed to evaluate solutions related to energy efficiency and technological choices [8]. For example, Scout, a software program developed by the U.S. Department of Energy, estimates the national energy and carbon savings, as well as the operating cost impact potential of a wide range of energy efficiency measures in U.S. buildings. Going forward, building scientists must integrate sufficiency measures into existing assessment approaches. These will generate estimates of the overall sufficiency–efficiency potential of different decarbonization strategies, thereby supporting data-driven policy decisions. Additionally, social scientists should quantify the net effects and strength of relationships between energy sufficiency and human and community well-being, under different assumptions and contexts. This would require data-driven approaches leveraging historical data and collecting new datasets from different settings, such as populations residing in different geographical locations, or belonging to diverse socio-economic groups, and triangulating quantitative with qualitative insights.

Secondly, social scientists, particularly cultural anthropologists, sociologists, and psychologists must identify the barriers and enablers of energy-sufficient behavior at different scales, ranging from individual, household, and institutional to the community and societal level to support the development of effective energy policies and interventions. For instance, the following may encourage more sufficient behaviors: a flexible clothing policy for office building users; building system controls with flexible operations such as partial-space/partial-time heating or cooling; thermostat setpoints based on the adaptive comfort theory[9]. Additionally, policy makers must consider the interaction effects of policy and technology on energy-sufficient behaviors. For instance, a feed-in-tariff policy (payment or credit given by the utilities to private renewable energy producers such as homeowners to sell back the over-produced electricity to the grid) with no or limited payment incentives often leads to higher energy use, or even uptake of unessential energy-intensive appliances within solar-powered homes. This can further exacerbate energy inequity, and such policies often exclude renters and low-income households who cannot afford the upfront costs.

Thirdly, researchers must model and examine sectoral interdependencies. Building sufficiency measures may create rebound or spillover effects in other sectors such as transportation, manufacturing, or food. Previous studies have estimated 5 to 15% rebound effects within households for energy sufficiency actions affecting heating and electricity[10]. Environmental scientists, economists and energy system modelers must adopt multi-sectoral dynamics modeling to understand these interdependencies. For instance, occupants may use the cost savings from lower energy bills or ownership of fewer home appliances to pay for a flight for their next vacation, which could offset the net carbon savings. Social scientists must also identify potential causes of spillovers, e.g., rebound or prebound effects such as weak environmental values or inconsistent behavior, as well as possible solutions to limit them.

Fourthly, governments must collaborate with community-based organizations and social scientists to develop innovative behavioral change instruments by utilizing the theories and empirical understandings from psychology, sociology, and behavioral sciences. This could include, for instance, co-designing choice architecture for promoting energy-sufficient behaviors or identifying the root causes of cognitive dissonance for increasing the adoption of efficiency measures, as well as ethnographic research involving trusted frontline service providers. Lessons from successful energy conservation campaigns such as Japan's 'Setsuden' movement or 'Super Cool Biz' could also be utilized. Authorities must also leverage technological advancements along with social media and edutainment for altering human behavior, although they are potentially less available to energy consumers in hardship or those in the Global South.

Overall, we argue that capping the rising energy consumption through sufficiency-oriented human behavioral changes and different lifestyle choices is the key to ensuring sustainable, equitable, effective, and timely decarbonization of the buildings sector. We re-emphasize the need to integrate sufficiency in the broader building decarbonization strategy to stay within the energy and carbon emission planetary boundaries while improving upon human health and well-being. Moreover, we advocate an interdisciplinary approach to operationalize sufficiency that should be supported by enabling technological and policy interventions. A systemic change to focus on energy sufficiency first is the most promising approach to decarbonize the buildings that we live and work in - and ultimately reduce our impact on this planet.

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Competing interests

The authors declare no competing interests.