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Analysis

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Small increases in material stocks to achieve decent living standards globally

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Global inequalities in resource use leave billions below decent living standards (DLS)—a proposal of universal minimum service levels required to meet essential human needs. Although research has examined the energy use and greenhouse gas emission implications of achieving universal DLS, little is known about the necessary expansion of societies' material stocks in buildings, infrastructure and machinery. Here we estimate that closing global DLS gaps would require an increase of approximately 12% in the existing material stocks of society, if efforts to expand these stocks are devoted exclusively to meet DLS. At current construction rates, this could be accomplished by 2030. However, if historical trends of unequal growth of material stocks driven by demands beyond DLS persist, the material stock requirements for DLS could increase tenfold, risking the achievement of sustainable development and climate change mitigation goals. To achieve DLS for all while limiting environmental pressures, it is essential to prioritize expansion of material stocks for closing DLS gaps and to critically asses stock expansion for demands beyond DLS—especially in affluent regions. Such a strategy could ensure universal DLS at more sustainable resource use levels.

Around 9% of the global population lives in extreme poverty on less than US$1.90 per person per day[1]. Many more live below service levels that enable decent transport (64% of the global population), sanitation (48%), drinking water supply (36%), housing (30%) and education (18%)[2]. Meanwhile, global resource use continues to rise, driving greenhouse gas (GHG) emissions and biodiversity loss[3,4]. Even today, most global resource use supports the lifestyles of the world's affluent and middle-classes, whereas resource use of the poorest remains very low[5–8].

To address poverty and unsustainability, the United Nations established the Sustainable Development Goals (SDGs) for 2030. Many SDGs link directly to the provision of basic needs (for example, SDG 2: Zero Hunger) and sustainable resource use (for example, SDG 12: Sustainable Consumption and Production), but these dimensions are not explicitly connected.

We address this gap by examining the material requirements of achieving decent living standards (DLS)—a proposal for universal minimum service levels needed to meet essential human needs[9]. DLS can be understood as the social floor within sustainable consumption corridors, that is, the minimum material requirements to enable a good life for all while staying within ecological limits[10]. DLS encompass ten need-dimensions aligned with the SDGs, including: nutrition (goal 2), health care (goal 3), education (goal 4), clean water, sanitation and energy (goals 6 and 7), information and communication (for example, goal 9), air quality (goal 11.6), housing and transport (goals 11.1 and 11.2), freedom to gather/dissent (goal 11.7) and other essential services needed to overcome multidimensional poverty (goal 1). Crucially, DLS focus on physical service demands, which enables assessment of the resource use implications of achieving minimum human needs and

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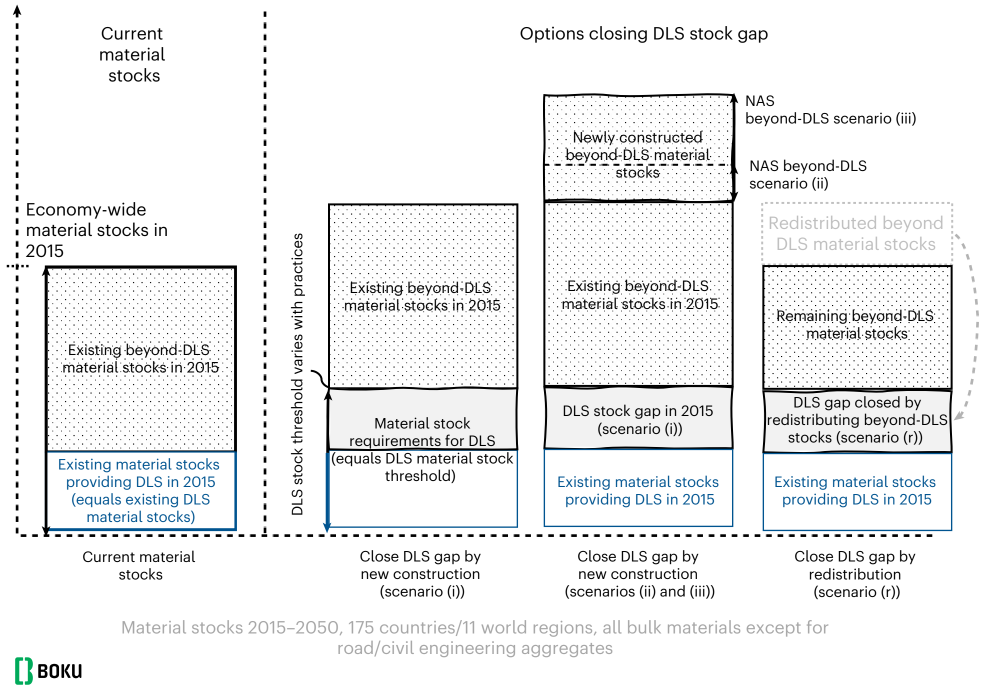


Fig. 1 | Overview of currently existing material stocks partitioned into DLS and beyond-DLS material stocks (left bar), as well as options for closing DLS stock gaps to reach DLS stock thresholds which provide DLS for everyone (right three bars). The DLS stock gap needs to be filled either by new construction (scenarios (i)–(iii), net stock additions (NAS)) or repurposing and redistribution of existing beyond-DLS stocks (scenario (r)). Scenario (i) simply fills the DLS stock gap, while in scenarios (ii) and (iii), this process is accompanied by net additions of beyond-DLS stocks following past patterns of stock buildup ('Material stock additions for closing DLS gaps' section in Methods). Right three bars: the curved lines surrounding the additions of DLS stock gap and beyond-DLS stocks illustrate that the mass of stocks required to achieve DLS for all depends on local/national/regional demography, geography, practices and material intensities/efficiency and varies with changes in these elements ('Existing DLS material stocks and gaps' section in the Methods for details).

their effect on environmental goals such as SDG 13 (climate action) and 15 (life on land).

Recent research suggests that providing universal DLS to those currently deprived would require only moderate additional energy use[2,11,12] and associated CO_2 emissions[6,13,14]. Global provision of DLS could by 2050 require less than half of today's annual final energy use[2,12] or around one third of 2040/2050 energy projections[2,14]. Without decarbonization, global CO_2 emissions to provide 'basic services' to all could rise by 15–26% compared with 2018 levels[6] and by 39% relative to 2019 levels to provide DLS for all[13,15] (Supplementary Information section 2.1). With decarbonization these emissions could be greatly reduced[6,13,14]. Given the shrinking carbon budget under the Paris Agreement, recent research stresses the need to jointly pursue universal DLS and ambitious climate policy[14].

Beyond energy and emissions, the provision of DLS depends on long-lived structures and products such as buildings, infrastructure, machinery and appliances, which represent socio-economic stocks of engineered materials such as steel, concrete, timber or plastics[16,17]. These material stocks both shape societies' well-being and environmental pressures, as evidenced by their contribution to two thirds of the SDG targets[18]. They deliver essential services to society such as shelter, mobility or communication[19] but also require 37% of global primary energy supply and more than half of annual global raw material extraction for their construction and maintenance[20,21]. Extracting and processing these raw materials causes 23–35% of global GHG emissions[22,23] and threatens ecosystems and biodiversity[24,25]. In addition, due to their longevity, these stocks lock in energy and material flows required for service provision in the long-term[26,27]. Therefore, while targeted growth of material stocks in some regions is pivotal to provide sufficient services for human well-being[18,28], the unchecked expansion of material stocks could easily jeopardize internationally agreed-upon climate goals[21,29].

Recently, Veléz-Henao and Pauliuk[30] estimated per-capita material stocks required to achieve DLS at 43 tons/capita[30]. However, their study does not consider the already existing material stocks or distinguish those for DLS from beyond-DLS uses (that is, use of service or product levels higher than DLS or outside of the DLS consumption basket—such as very spacious housing or luxuries, respectively). The geographic distribution of DLS material stock requirements and by when these could be met were also not assessed.

Here, we estimate the existing socio-economic material stocks used in 2015 for providing current levels of DLS globally and the additional stocks required to close DLS gaps for each country (Fig. 1). We compare these with estimates of the existing stocks that provide services beyond DLS, which we present for 11 world regions. Subsequently, we explore three scenarios for closing global DLS gaps by new stock construction and, one additional scenario investigating gap closing by repurposing and redistributing existing material stocks. Comparing these results allows us to assess material stock requirements and timelines for achieving universal DLS.

To estimate the existing DLS stocks and gaps, we combine the latest research on DLS status indicators for the dimensions nutrition (calories, stoves and fridges), shelter (housing and thermal comfort), mobility (vehicles, infrastructure), health, education, water, sanitation, communication and clothing for the year 2015[2,9,14], with detailed bottom-up modelling of material stock intensities for DLS service units resolved for 46 product groups and 29 materials assuming current technologies[30,31]. We account for regional practices ('routinized type(s) of behaviour')[32] in diets, transport modal shares, vehicle occupancy, housing types, schooling population and material intensities to estimate the material stocks that provide current levels of DLS and explore the stocks required to close DLS gaps assuming various practices and technologies ('Existing DLS material stocks and gaps' section in the Methods). To estimate the existing material stocks for demands beyond

DLS, we subtract existing DLS stocks per product and material group from novel country-level estimates of economy-wide material stocks (representing all uses in the economy) covering 14 product groups and 21 material types comprising over 99% of overall primary material use by mass[8,20]. The scenarios for closing DLS gaps assume stock additions dedicated solely to DLS stocks (scenario (i)), as well as those for beyond-DLS uses following regional (scenario (ii)) and global (scenario (iii)) patterns, and repurposing and redistributing existing beyond-DLS stocks within regions and product groups (scenario (r)). To explore when DLS gaps might be closed across scenarios, we extrapolate the historical speed of constructing new material stocks based on data for the period 2005–2016.

Throughout our analysis, we express existing DLS material stocks and their gaps as per-capita averages referencing countries' entire population (noting that in reality the stock gaps only affect the deprived part of the population; 'Existing DLS material stocks and gaps' section in the Methods) and refer to total material stocks (summed over all materials) if not stated otherwise. We refer readers to the Methods and Supplementary Information section 1 for methodological details.

Results

Global inequalities in material stock levels providing DLS

Most affluent countries in the global north already have the material stocks to provide DLS for nearly their entire populations. Expressed as national per-capita averages, many of these countries already have >95% of the stocks (summed over all materials) required to meet DLS thresholds (Fig. 2a). However, larger DLS stock gaps remain in the former Soviet Union and Eastern Europe.

By contrast, many countries of the global south have less than half of the material stocks required to achieve DLS. In sub-Saharan Africa, thirty countries have less than 40% of the necessary stocks. The DLS stock gaps in this region are the largest ones worldwide, averaging 22 tons per capita, closely followed by centrally planned Asia and South Asia with gaps of 13 and 12 tons per capita, respectively (Fig. 2b).

Across world regions, the largest material stock gaps exist for shelter, followed by mobility, socialization (education and communication) and health—though the order varies by region (Fig. 2a). The estimates shown in Fig. 2 refer to the total stock requirements, aggregated across all material types, which assumes substitutability between different material groups—the ability to use different materials interchangeably to fulfil similar functional roles. When disaggregated by material groups of biomass, fossil-based, metals and non-metallic minerals, a similar picture emerges (Supplementary Information section 2.2).

The DLS stock gap estimates presented above assume that current national/regional practices (for example, diets and transport choices; 'Existing DLS material stocks and gaps' section in the Methods) are maintained when closing DLS gaps. Under this assumption, the regional per-capita stock thresholds required to provide DLS to everyone range from 29 to 50 tons per capita (Fig. 2b, blue plus white filled bars, global average 38 tons per capita). We find the highest DLS stock thresholds in centrally planned Asia at 50 tons per capita, and the lowest in South Asia at 29 tons per capita (Fig. 2b). Per country, we find a range from 26 tons per capita required in Bangladesh to 63 tons per capita in Estonia.

The variation in DLS stock thresholds across regions and countries can be attributed to differences in demographic structure (for example, calorific nutritional requirements differ by age and gender)[2], geographic conditions (for example, population density influences mobility needs), regional practices such as diets, mobility modes and housing forms, as well as regional material intensities. For example, regions with heavy construction, animal-based diets and car-dependent mobility exhibit higher material stock demands, compared to those with lighter construction, plant-based diets and public transit (Supplementary Information section 2.3). Higher material stock levels and stock-intensive practices also correlate with higher affluence (Supplementary Information section 2.3). The regional differences of DLS stock thresholds are explained by differing household size (explaining 17% of variance), building material intensities (15%), diets (14%), other material intensities (10%), modal shares (6%), differing mobility needs due to population density (5%) and patterns of energy use and generation (4%), together explaining 98% of the variance in DLS stock thresholds across regions (Supplementary Information section 2.4). Here, household size influences stock thresholds through per-capita floorspace and household appliance needs, based on the assumption that larger households require less space and fewer appliances per person (for example, due to shared common areas)[2,11].

Changes in practices and material efficiency alter material stock requirements for DLS

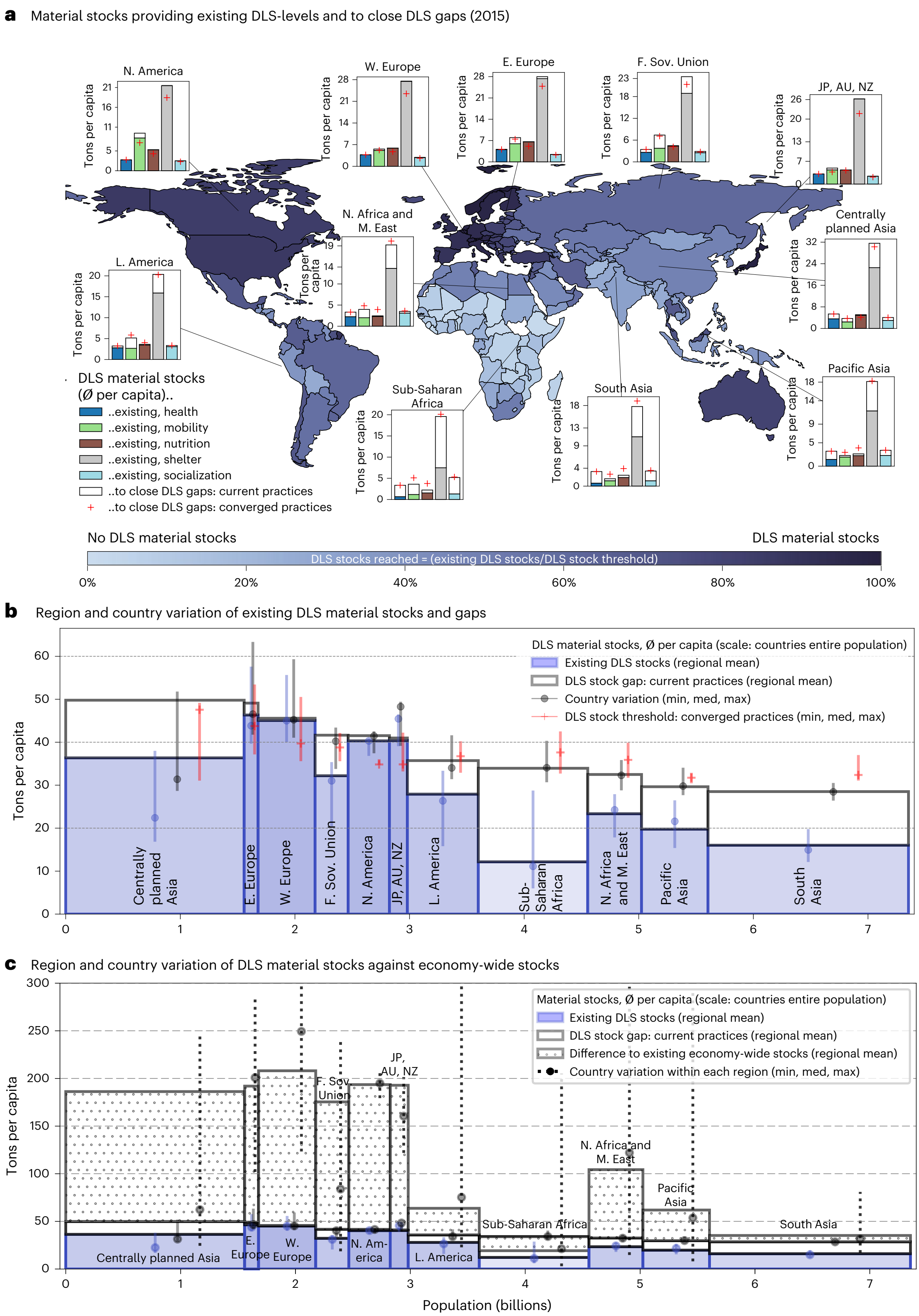
If current practices persist, efforts to close DLS gaps risk perpetuating material-intensive, opulent practices in affluent regions and material-efficient, basic ones in low-income regions (Supplementary Information section 2.3). To address this, we assess DLS stock thresholds under globally converged practices—assuming 2015 median household sizes, low meat diets and mobility modes consistent with the International Energy Agency Beyond 2 °C scenario (which assumes rapid decarbonization), following recent work[12,30].

Under these converged practices, regional DLS stock thresholds become more aligned, ranging from 32 to 48 tons per capita (Fig. 2b, red cross, global average 39 tons per capita). However, the effects of converged practices are asymmetric. In parts of the Global

Fig. 2 | Total material stocks (summed over all materials) providing DLS around the world in the year 2015—expressed as national or regional per-capita average fulfilment, based on the entire population of a country or region. a, The share of already existing material stocks providing DLS (existing DLS stocks) compared with the level of material stocks required to reach DLS for all (DLS stock threshold): the world map shows countries that reach DLS stock thresholds in dark blue and countries with large DLS stock gaps in light blue (assuming the maintenance of current national/regional practices to close current DLS stock gaps); the bar charts show the existing DLS stocks and DLS stock gap by need dimension for 11 world regions, the bars show estimates assuming maintenance of current practices and the red cross shows the DLS stock thresholds assuming globally converged household sizes (median of countries in 2015), low meat diets[30,51] and mobility shares following the Beyond 2 °C scenario of the IEA[50]. The need dimension socialization combines needs for education and communication, and nutrition shows stocks for production facilities and equipment. **b**, Currently existing material stocks providing DLS (blue) and DLS material stock gaps assuming the maintenance of current national/regional practices (black outline with white fill) or with converged practices (red cross), together making up the amount of material stocks required per world region to reach DLS stock thresholds: mean (bars/cross), median (dots) and minimum–maximum of countries in regions (lines). The DLS material stock gap corresponds to scenario (i) in Fig. 1. The amount of material stocks required to reach DLS for all differs across regions and countries due to differing regional demographic and geographic conditions, as well as differences in practices and material efficiency. **c**, The currently existing material stocks providing DLS (blue) and DLS material stock gap (black outline with white fill), in contrast to the stock level difference to currently existing economy-wide stocks (black outline with white hatched fill). 'min, med, max' represents the minimum, medium and maximum of countries in regions. Ø represents the average. For figure data, see Supplementary Data 1 tabs: Fig2a_map_countries, Fig2a_map_reg_stocks_dim, Fig2bc_stock_distr_countr, Fig2b_stock_distr_stats. The sample size (n = countries) for statistics in **b** and **c** are (Table 1 in the Supplementary Information): centrally planned Asia: 7, Eastern Europe (E. Europe): 16, Western Europe (W. Europe): 21, Former Soviet Union (F. Sov. Union): 12, North America (N. America): 3, Japan, Australia, New Zealand (JP, AU, NZ): 3, Latin America (L. America): 28, sub-Saharan Africa: 46, North Africa and Middle East (N. Africa and M. East): 19, Pacific Asia: 12, South Asia: 8. The world map is from naturalearthdata.com.

North, such as North America, DLS stock thresholds fall below existing DLS stock levels (Fig. 2b, red cross) because converged practices are more material-efficient than current ones (for example, modal and diet shift reduce thresholds by 4% and 2%, respectively) (Extended Data Fig. 1). Conversely, many global south regions see DLS stock thresholds increase because converged practices are more material intensive than current ones (for example, the same shifts increase thresholds by 4% each in sub-Saharan Africa).

Further reductions in DLS stock thresholds (on top of converged practices) are possible through additional practice shifts and material efficiency. Promising strategies include wooden and lightweight construction (≥28% reduction across regions), increased household size



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(~8%), vegan diets (4–6%) and reduced motorized individual mobility (1–2%). The latter potential may be underestimated due to limitations in modelling mobility infrastructure in life cycle assessments (LCAs) ('Limitations' section in the Methods). Nevertheless, some changes may increase requirements, such as smaller household size (~20% increase) or transitioning to cleaner but more stock-intensive renewable energy systems (1–45% increase) (Supplementary Information section 2.5).

Overall, while practice changes and material efficiency can reduce DLS stock thresholds, greater potential may lie in addressing the much larger part of existing economy-wide stocks in the global north that does not serve DLS ('DLS material stocks against other uses' section and Fig. 2c). By contrast, many global south regions have low existing economy-wide stocks. For sub-Saharan Africa, these are even smaller (19 tons per capita on average) than DLS stock thresholds (34–38 tons per capita).

DLS material stocks against other uses

In 2015, we estimate existing global DLS material stocks at 194 Gigatons, representing 27% of economy-wide material stocks in the same year (710 Gigatons, excluding aggregates in road and civil engineering foundations) (Fig. 3a). Shelter is by far the largest constituent of DLS stocks (Fig. 2a), as are buildings and non-metallic minerals from a product and materials perspective (Fig. 3a). Across world regions, the share of existing DLS material stocks varies widely. For global north regions, North Africa, the Middle East and centrally planned Asia, this comprises between 20% and 26% of regional economy-wide stocks, whereas it is much higher at 34–48% for most global south regions and highest for sub-Saharan Africa at around 62% (Fig. 3b).

The comparatively small global share of DLS stocks implies that around two thirds of existing economy-wide stocks globally are not used for providing DLS but services beyond DLS (Fig. 3a); we refer to these as 'beyond-DLS stocks'. Large beyond-DLS stocks have accumulated primarily in the global north and centrally planned Asia (Fig. 3b). The largest product groups of these beyond-DLS material stocks (by mass) are civil engineering comprising dams, tunnels and bridges, subways, harbours, communication, power, water and sewage infrastructure (36% globally, 21–61% regionally), residential buildings (31% globally, highest in centrally planned Asia at 48%), non-residential buildings (26% globally, highest in South Asia at 44%) and road and rail infrastructure (6% globally, highest in North America at 31%) (Fig. 3a,b).

Material stock additions for closing DLS gaps

We explore three hypothetical scenarios for closing DLS gaps by expanding existing material stocks and a fourth scenario, exploring the repurposing and redistribution of already existing beyond-DLS stocks (Table 1).

In scenario (i), build DLS stocks only, we assume all new construction focuses solely on material stocks which close DLS gaps. Here, we estimate the additions required under current national/regional practices ('Existing DLS material stocks and gaps' section in the Methods) at just 12% of the global economy-wide material stocks existing in 2015 (Fig. 3a, bar (i)). This corresponds to 82 Gigatons of additional stocks, of which most comprise non-metallic minerals (87%), metals (10%) and biomass (3%) (Extended Data Fig. 2). These are primarily needed for the construction of residential buildings (38%) for shelter, non-residential buildings (31%) for educational, health care and industrial infrastructure; roads and railways (17%) for passenger and freight transport; and civil engineering (9%) for supporting infrastructure. Under converged practices, the global DLS stock gap increases to 93 Gigatons or 13% of 2015 economy-wide stocks (Fig. 3a and Supplementary Information section 2.6).

For every ton of DLS stock in 2015, an additional 0.6–4 tons of beyond-DLS stocks exist, depending on the region (Fig. 3b)—potentially reflecting historic inequalities. In scenario (ii), build some beyond-DLS stocks, new DLS stock construction is proportionally linked to beyond-DLS stock buildup, based on each region's beyond-DLS-to-DLS stock ratio in 2015 (Fig. 3b). As a result, the net stock additions required to close DLS gaps rise to 33% of the global economy-wide material stocks existing in 2015 (Fig. 3a, bars (i) and (ii)).

In scenario (iii), build many beyond-DLS stocks, we assume that constructing new DLS stocks is linked to extensive beyond-DLS stock buildup. Under this scenario, all countries reach at least the economy-wide material stock levels found in countries currently achieving >95% DLS fulfilment—averaging 177 tons per capita and translating to 3–5 tons beyond-DLS stock per unit of DLS stock ('Material stock additions for closing DLS gaps' section in the Methods). These are predominantly high-income nations with substantial beyond-DLS stocks. The estimated net additions to stocks in this scenario reach 99% of 2015 economy-wide stocks (Fig. 3a, bars (i), (ii) and (iii)). Thus, if countries with large DLS gaps follow high-income countries development paths, we estimate that economy-wide stocks could double from the current ~700 to 1,400 Gigatons (Fig. 3a).

Scenario (r), repurpose and redistribute. Instead of new construction, beyond-DLS stocks could be repurposed and redistributed to close DLS gaps. Assuming that regional DLS stock gaps (Fig. 3b, bar (i)) can be closed by repurposing and redistributing beyond-DLS stocks of the same product group (for example, repurposing office buildings to schools), several regions could close DLS stock gaps with minimal new construction, assuming free movement of people within regions (Fig. 4). While merely indicative, our results suggest that DLS gaps could be closed entirely by redistribution in much of the global north (for example, Western Europe) and partially for North Africa and the Middle East (94%) as well as Asia and Latin America (>60%). By contrast, sub-Saharan Africa could only close about 20% of DLS gaps by redistributing beyond-DLS stocks, because of its large gaps and limited beyond-DLS stocks (Fig. 4, bars). For the larger DLS stock gap under converged practices, the proportions only change slightly (Fig. 4, red cross).

Timing of closing DLS gaps

In the past decade (2005–2016), the speed of new construction of total stocks (summed over all materials) was low to medium and increasing in regions with large DLS gaps (purple, 0.7–2.8 tons per capita per year except centrally planned Asia, North Africa and Middle East) (Fig. 5a). It was also low to medium but declining in regions of the global north (grey, 0.7–4.2 tons per capita per year) and rapid and peaking for centrally planned Asia (grey, 12.9 tons per capita per year)[8]. Extrapolating these trajectories (except for centrally planned Asia, where it is assumed to decline at −1% per year, 'Timing of closing DLS material stock gaps' section in the Methods), we approximate when DLS gaps could be closed, considering the estimated construction needs across scenarios (i)–(iii) and regional variations in the speed of construction. We exclude scenario (r), repurpose and redistribute from this timing analysis, as it hinges on political and socio-economic factors rather than biophysical ones, which are beyond the scope of this work.

Extrapolating historical regional construction speeds. At regional speed (Fig. 5b), global DLS material stock gaps could close by ~2030, in line with the SDG timeline, if construction and manufacturing focuses solely on DLS stocks (Fig. 5c, dark-green dashed line, scenario (i)). However, if construction also supports some beyond-DLS stock growth reflecting historical trends (scenario (ii)), achieving DLS would be delayed until ~2036 (Fig. 5c, dark-yellow dashed line). Under a scenario where regions with large DLS gaps replicate patterns of trickle-down development of wealthier regions (scenario (iii)), DLS might not be achieved by 2050, with only ~93% of the required material stocks in place by that time (Fig. 5c, dark-red dashed line).

Extrapolating historical global average construction speed. As global average speed (Fig. 5b) exceeds most global south regional rates, maintaining it would close global DLS gaps much earlier (Fig. 5c,

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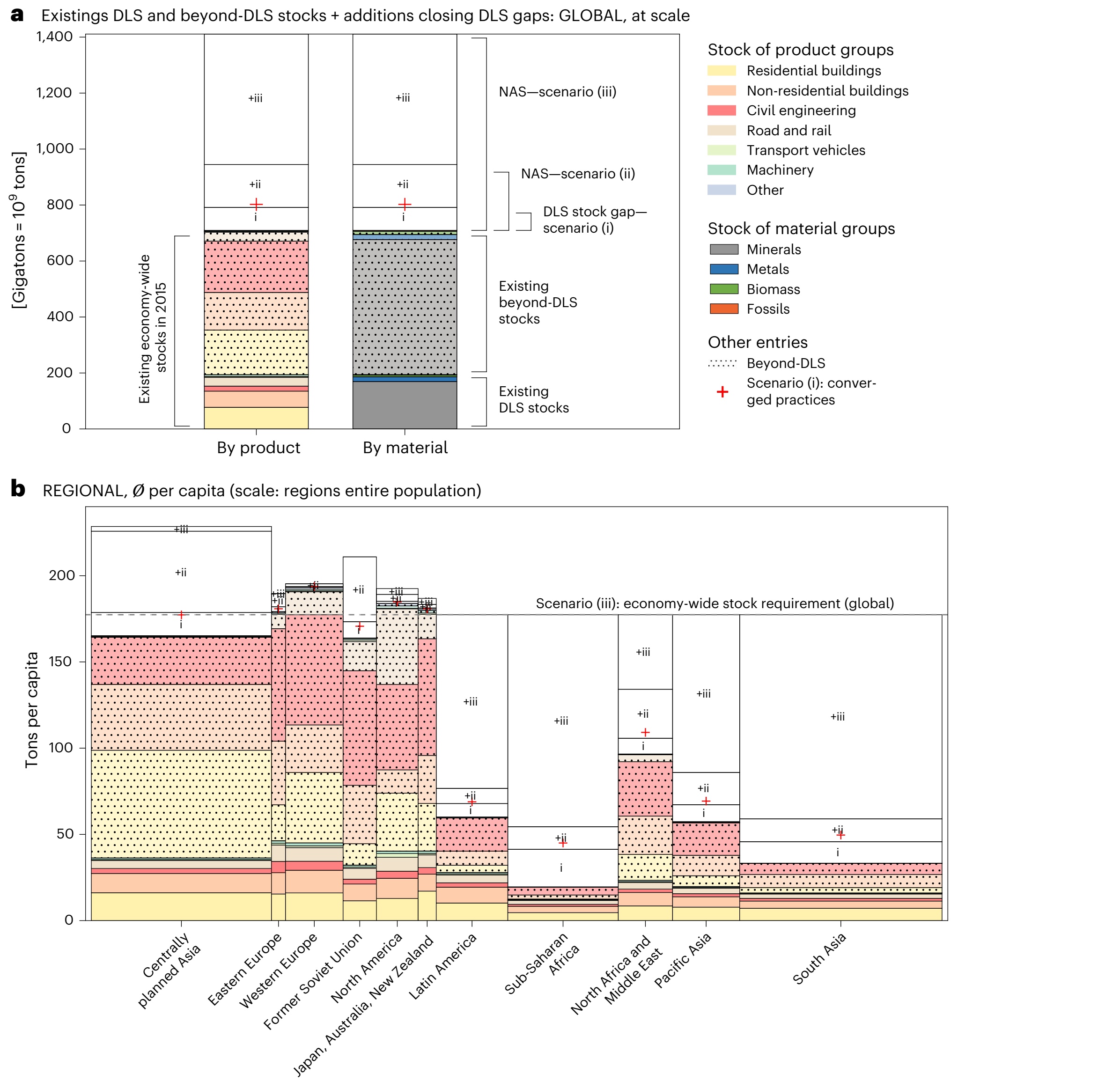

Fig. 3 | Estimates of existing material stocks in 2015 providing DLS material stocks (coloured bars) and beyond-DLS material stocks (hatched coloured bars), as well as the additions to material stocks required to close DLS gaps under different scenarios (white bars). a,b, For the Globe (**a**) and for 11 world regions (**b**). The material stock additions to close DLS gaps are of different size depending on whether only DLS stocks or also beyond-DLS stocks are built when closing DLS gaps: scenario (i): build DLS stocks only—shows the required additions if only building DLS stocks (bar (i) represents the current national/regional practices; the red cross represents the converged practices) (Table 1); scenario (ii): build some beyond-DLS stocks shows required additional beyond-DLS stocks assuming that new DLS stock construction is proportionally linked to beyond-DLS stock buildup, following the 2015 beyond-DLS-to-DLS stock ratio within each world region (as in **b**) as part of broader economic development; and scenario (iii): build many beyond-DLS stocks shows required additional beyond-DLS stocks assuming that new DLS stock construction is linked to extensive beyond-DLS stock buildup, reaching the overall material stock levels observed in countries achieving approximately 95% DLS fulfilment—predominantly high-income nations with substantial beyond-DLS stocks (see 'Material stock additions for closing DLS gaps' section in the Methods for details). The stock additions to close DLS gaps are additive: in the worst case, stock buildup to close DLS levels would take up the magnitude of bars (i), (ii) and (iii). The sum of DLS- and beyond-DLS material stocks gives the size of economy-wide stocks[8] in 2015 (excluding aggregates in roads and civil engineering foundations). The product category 'other' comprises textiles, lamps, printed matter, furniture and products not elsewhere specified. Ø represents the average. See the Methods for methodological details. For figure data, see Supplementary Data 1 tabs: Fig3_global_material, Fig3_global_product, Fig3_regio_mater_prod, Fig3_stockGapCurr_RMDP.

solid lines). DLS could be reached around 2020, 2027 and 2042, under scenario (i) (green), scenario (ii) (yellow) and scenario (iii) (red), respectively. However, we may overestimate the speed because we only extrapolate total material stock, implicitly assuming perfect substitutability across material types. Faster rates may be required for slower-growing material groups such as biomass and metals that lag behind other material types (Supplementary Information section 2.7). Extrapolations for these material groups suggest DLS is achievable only if their construction speeds increase to at least the global average.

Assuming the slightly higher DLS material stock gap size under converged practices ('Material stock additions for closing DLS gaps' section) the achievement of DLS stock thresholds starts slightly lower and would be closed marginally later (Fig. 5c, light-colour-shaded lines).

Discussion

Although our scenarios are stylistic, they highlight that reducing stock use inequalities and directing new construction towards meeting DLS

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Table 1 | Description of the modelled scenarios for closing DLS gaps with regards to material stock construction/redistribution

Scenario label	Scenario description
Scenario (i)—build DLS stocks only	Assumes that DLS gaps are closed by building solely DLS material stocks (stocks which provide DLS, equation (5)). This scenario reduces within- and between-country inequalities by assuming construction of material stocks for the DLS deprived population (see Supplementary Data 1 tab Fig3_regio). We model two cases for scenario (i):
	- Following current national/regional practices, which assumes construction of DLS stocks on the basis of maintaining national/regional practices estimated for 2015
	- Following converged practices, which assumes construction of DLS stocks based on converged practices, that is, 2015 median household sizes, mobility modes consistent with the IEA Beyond 2 °C scenario (which assumes rapid decarbonization)[50], the median of 2015 vehicle occupancy and healthy diets with low meat consumption[30,51]
Scenario (ii)—build some beyond-DLS stocks	Assumes that new DLS stock construction is proportionally linked to buildup of some beyond-DLS stocks, following the ratio of beyond-DLS to DLS stocks in 2015 and within each world region as part of broader economic development. This scenario might reduce within-country inequalities depending on who will have access to beyond-DLS stocks (if these are going to the wealthy, inequality might actually increase; illustrated in Fig. 3, for example, by scenario (ii) beyond-DLS stocks being much larger than scenario (i) DLS stocks in North Africa and the Middle East) and slightly reduces stock level inequalities between countries at substantial material stock growth (see Supplementary Data 1 tab Fig3_regio).
Scenario (iii)—build many beyond-DLS stocks	Assumes that new DLS stock construction is linked to extensive beyond-DLS stock buildup. In this scenario, all countries reach at least the average economy-wide material stock levels found in countries currently achieving >95% average DLS fulfilment—estimated at 177 tons per capita (see 'Material stock additions for closing DLS gaps' in the Methods for details). These are predominantly high-income nations with substantial beyond-DLS stocks. The scenario substantially reduces between-country inequality at the expense of a doubling of economy-wide material stocks from 2015 (see Supplementary Data 1 tabs Fig3_global_material and Fig3_regio). Similar to scenario (ii), the effect on within-country inequality depends on who gains access to beyond-DLS stocks.
Scenario (r)—repurpose and redistribute	Assumes that DLS stock gaps (equation (5)) are closed by repurposing and redistributing beyond-DLS stocks of the same product group existing in 2015 within world regions (for example, repurposing office buildings to schools). This scenario reduces within-country inequality while between-country inequality does not change.

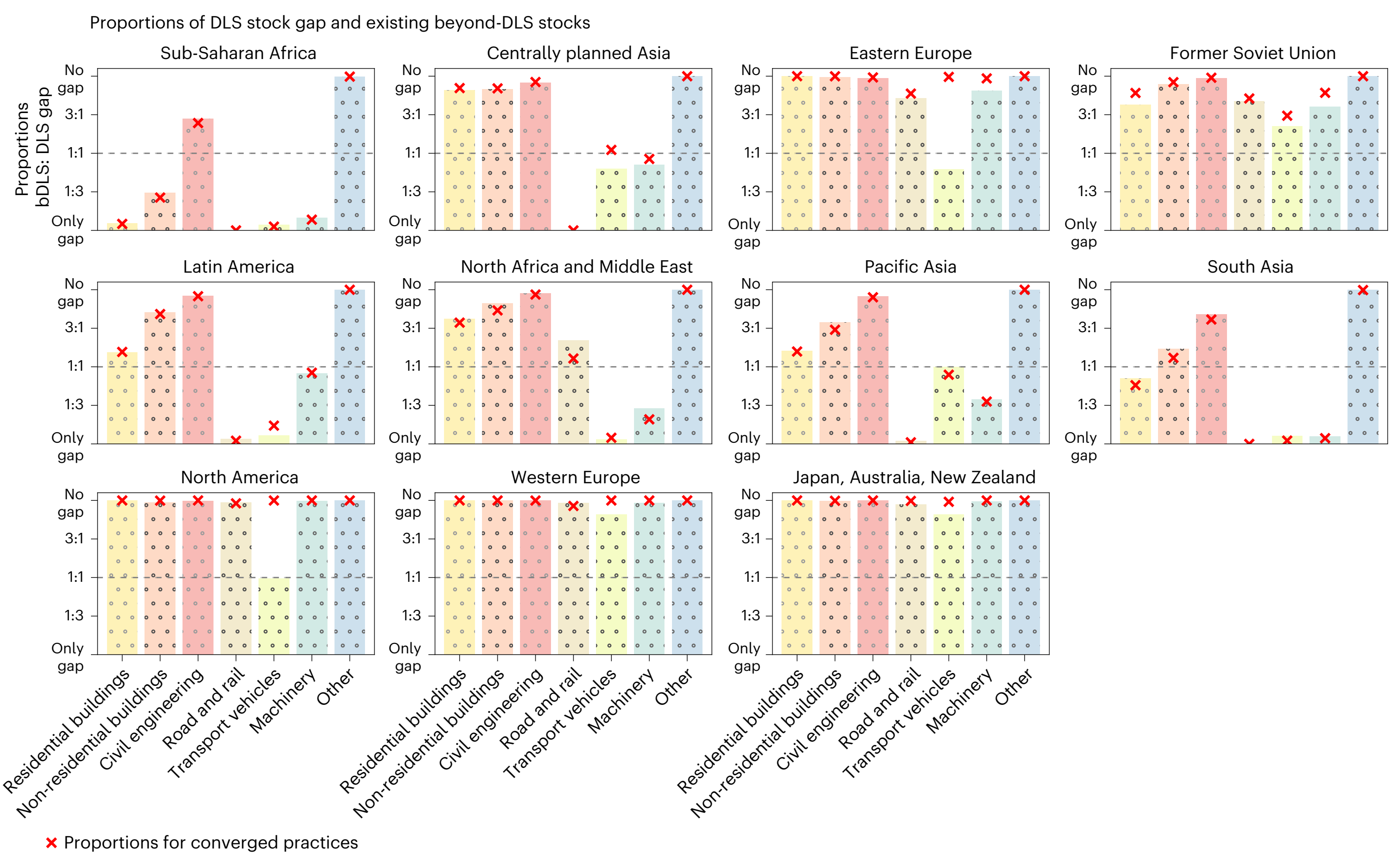

Fig. 4 | Relative size of the DLS material stock gap in comparison to existing beyond-DLS material stocks per world region and product group, which can inform about the possibility of repurposing beyond-DLS to DLS stocks. The 1:1 value on the *y* axes means that DLS stock gap and beyond-DLS stocks are of equal size. The bars reflect the proportions under maintenance of current practices, while the red cross indicates the proportion when assuming converged practices—both of which affect the size of the DLS stock gap and thereby the proportions between the gap and beyond-DLS stocks shown here. Please note that due to the limitations in matching the differing modelling techniques for DLS gaps and beyond-DLS stocks ('Limitations' section in the Methods) these results should be regarded as rough estimates with currently best available data. An example of a resulting possible modelling artefact is the potential of closing DLS stock gaps by redistributing beyond-DLS stocks below 100% for North America—it seems unlikely that this region lacks the transport machinery to close DLS gaps. For figure data, see Supplementary Data 1 tabs: Fig4_DLS_bDLS_prop_curr, Fig4_DLS_bDLS_prop_conv.

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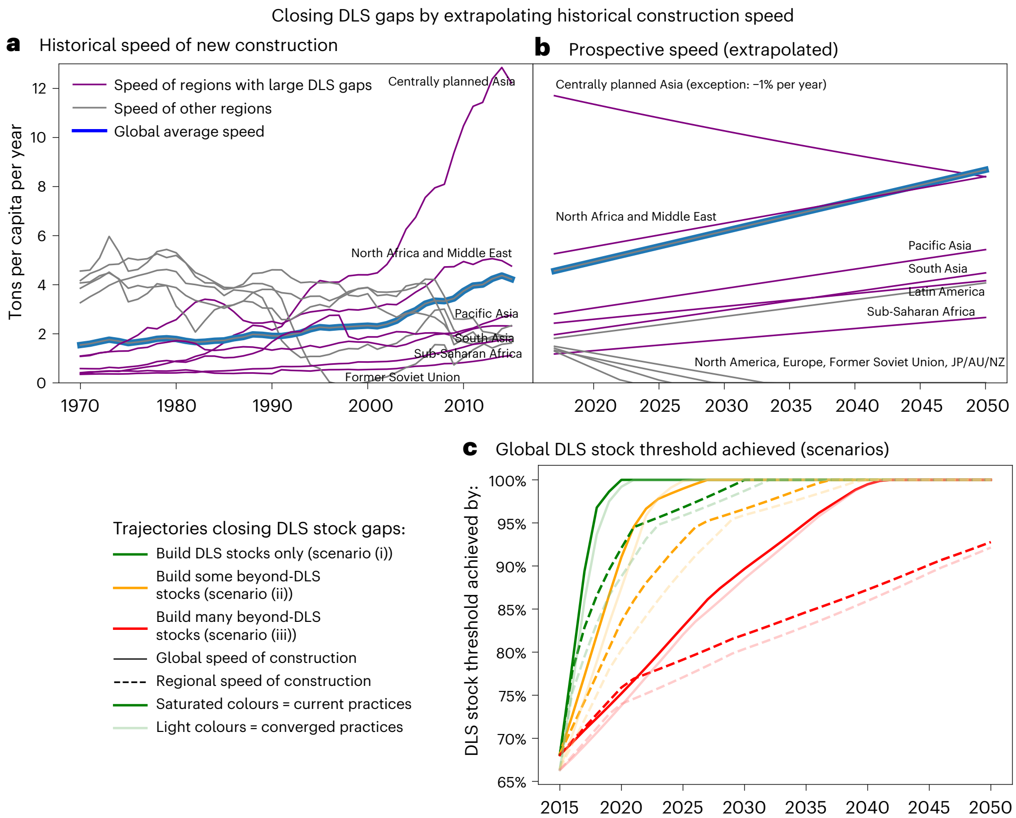

Fig. 5 | Historical speed of new material stock construction and timing of DLS gap closure assuming extrapolated past construction speed. a,**b**, Historical (**a**) and future (**b**) extrapolated speed of new construction (net additions to stock per capita for sum of biomass, fossil-based materials, metals and minerals based on Wiedenhofer et al., 2024)[8] per world region with large DLS gaps (purple lines) and with smaller gaps (grey lines), as well as the global population-weighted average (blue line). We do not show negative net stock additions (NAS, which correspond to shrinking overall stocks because stock demolishment is higher than new construction) in **a** and assume a minimum of zero new construction in **b**. JP/AU/NZ, Japan, Australia and New Zealand. **c**, The temporal trajectory of closing global gaps in DLS for maintenance of current national/regional practices (saturated coloured lines) and converged practices (light coloured lines) at two different speeds (dashed line, at regional per-capita speed of new construction for each world region, and solid line, average population-weighted per-capita speed of new construction for the Globe, assumed for all world regions) and three different construction foci (green, scenario (i)—assumes construction of DLS material stocks only; yellow, scenario (ii)—assumes also building some beyond-DLS stocks maintaining regional patterns and estimates the accompanying beyond-DLS stocks according to regional ratios of existing DLS versus beyond-DLS stocks in 2015; red, scenario (iii)—assumes also building many beyond-DLS stocks following existing global patterns and estimates beyond-DLS stocks according to the country cross-section between economy-wide material stocks and the level of DLS reached in 2015 (see Table 1 for details). In **b**, we linearly extrapolated trends in construction speed from 2005 to 2016 for each world region and the global average, except for centrally planned Asia, for which we adopted potential Chinese developments at −1% per year based on indications in the literature detailed in Wiedenhofer et al.[59]. See 'Timing of closing DLS material stock gaps' section in the Methods for methodological details. The bend in the red curve of reaching DLS in **c** is the result of centrally planned Asia reaching DLS between 2019 and 2020, after which the development in the remaining world continues at a slower pace. For figure data, see Supplementary Data 1 tabs: Fig5a_speed, Fig5b_prospSpeed, Fig5c_closeGap_Glob_curr, Fig5c_closeGap_Glob_conv.

could serve as key leverage points for rapidly achieving universal minimum service levels (DLS) with relatively low material demand.

Feasibility of prioritizing and speeding-up expansion of DLS material stocks

Past trends suggest that prioritizing and accelerating DLS material stock construction is feasible. For example, Latin America reached high DLS by 2015 with relatively low beyond-DLS stocks (Figs. 2a and 3b), indicating prioritization. This aligns with existing literature on well-being outcomes at low resource use in this region[33]. Likewise, rapid construction in centrally planned Asia in the past decade and in the global north during the 1970s (Fig. 5a) demonstrates that elevated construction rates beyond those assumed in our analysis are possible.

In practical terms, such prioritizing faces biophysical and socio-economic constraints. Biophysically, sufficient industrial and manufacturing capacity is needed for material extraction and processing. China's infrastructure development in Africa under the Belt and Road Initiative demonstrates that industrial capacities can be partially transferred between regions[34]. However, prioritizing and speeding-up DLS gap closing requires large investments, supportive policies and effective governance. For example, decent housing for everyone could be advanced through social housing initiatives and zoning regulations. However, climate research[35] using governance projections indicates that weak governance is a substantial barrier[36]. Future work could incorporate these projections to assess the plausibility of DLS expansion.

Implications of reduced inequalities for lowering resource use needed to achieve DLS

Large inequalities are a substantial barrier for achieving universal DLS at low levels of resource use. Millward-Hopkins et al.[37] show that even modest inequality increases energy needs for DLS by 40%. While we do not model subnational inequalities, our findings echo this conclusion for material stocks. High beyond-DLS stocks coexist with persistent DLS gaps in some regions, indicating within-region inequalities (Fig. 3). Large inequalities also exist between regions—the global north currently averaging 181 tons per capita in material stocks, over four times the South's 42 tons per capita[8] (excluding centrally planned Asia, 163 tons per capita, Fig. 3). Replicating such unequal patterns during DLS expansion, could double existing economy-wide material stocks (Fig. 3).

While a 40% increase in annual energy use to meet DLS can be considered moderate, doubling material stocks presents a major climate challenge, as it increases demand for products from hard-to-abate industries[21]. Integrated assessment models estimate that achieving DLS under stringent climate mitigation policy could emit around 200 $GtCO_2$ until 2050, while maintaining some inequality[38]. Our own rough estimates, based on established methods[21] and assuming 2015 CO_2 intensities, indicate that material production alone could generate 28 $GtCO_2$ for constructing DLS stocks (scenario (i)) and around 236 $GtCO_2$ if global material stocks were doubled due to major construction of beyond DLS stocks (scenario (iii)). About 85% of these emissions are energy related and reducible through decarbonization; the rest are process emissions potentially harder to avoid.

Reducing these inequalities can enable the achievement of universal minimum service levels without escalating resource use. This may require repurposing and redistributing stocks within regions and saturating stocks in the global north and centrally planned Asia, prioritizing maintenance and efficiency. Theoretically, saved resources through this approach could support DLS stock growth in the global south, enable 'fairer' beyond-DLS stock levels and address historical unequal ecological exchange[39]. Moreover, this could free up GHG and resource budgets for global south development.

Inequality may be greater than discussed, as some beyond-DLS stocks in the global south support consumption in the North via exports, while the reverse seems unlikely[39], although solid evidence for this is still needed.

Potentials of resource-light lifestyles and material efficiency for reducing resource demand

Following global north developmental patterns—characterized by substantial buildup of beyond-DLS stocks, some of which support highly affluent lifestyles—would greatly increase global south material stock levels. Although such buildups beyond-DLS do not directly equate to excess and may be necessary to ensure a good life for all in the global south, they must remain within ecological limits at the global scale[40].

Lowering material intensities and adopting low-intensity lifestyles, through resource-light diets, mobility and shelter, can help to stay within limits by reducing material needs. For example, Veléz-Henao and Pauliuk[30] show that material footprints can drop through reduced animal products consumption (9–37% dependent on extent), public transport use (10%) and light/compact buildings (17–25%)[30]. Here, we have shown that the global average DLS stock requirements for current practices could be lowered through wood based and lightweight building construction (37% and 12% reduction, respectively), larger households reducing per-capita floorspace and appliances (9% reduction), vegan diets (4%) and lowering motorized transport demand (0.3%, probably underestimated due to limitations in LCA modelling, see 'Existing DLS material stocks and gaps' and 'Limitations' sections in the Methods) (Supplementary Information section 2.5).

In high-income regions, larger reductions can be achieved by transitioning to larger household sizes (up to 20% reduction), low meat and vegetarian/vegan diets (up to 2% and 3%/7% reduction, respectively) and low car use (up to 5% reduction) (Extended Data Fig. 1). Conversely, in many lower-income regions, such changes may initially increase material needs while enhancing living standards.

Therefore, while resource-saving opportunities are greatest in the global north due to high material intensities, practice and lifestyle shifts may also be important in the global south for shaping sustainable development trajectories.

Limitations and sensitivity of results

This is the first study quantifying DLS and beyond-DLS material stocks at country and regional levels. Despite using the best available data and methodology, limitations remain. These include the use of proxies to estimate DLS gaps due to data scarcity[2]; material intensities from LCA with limited representativeness, linear scaling and truncation errors[41]; mismatched data sources to distinguish DLS and beyond-DLS stocks; mixed consumption-based and production-based perspectives disregarding exact spatial patterns of DLS stocks; uncertainties in development of future practices and technologies; and use of current populations and national averages per capita that mask within-country inequalities. See 'Limitations' section in the Methods for further details.

Sensitivity analyses (Methods) show that changes in DLS thresholds, stock lifetimes and material intensities do not alter our main conclusions (Extended Data Table 1): first, if building material stocks solely for DLS, the stock gap is small compared with 2015 economy-wide material stocks (scenario (i): 8–15% variation versus 12% default). Second, reproducing within-country inequalities escalates resource use (scenario (ii): 28–37% economy-wide 2015 stocks versus 33% default; scenario (iii): 93–112% versus 99% default). Third, DLS achievement might be delayed when building beyond-DLS stocks (at past regional construction speeds DLS stock gap closed: 2027–2034 for scenario (i), 2035–2050 for scenario (ii) and not reached until 2050 for scenario (iii) across sensitivity cases). Finally, DLS stock thresholds diverge by more than factor two across sensitivity cases, illustrating potentials to reduce stocks by practice changes and material efficiency.

Further research directions

Although our scenarios show major savings from reducing inequalities and resource-light practices, DLS prioritization faces many constraints in the real world. Future work should investigate subnational DLS thresholds; improve data on within-country inequalities in service provision and resource use; examine the role of trade in shaping stock disparities; and develop integrated models that link, materials, energy, emissions, land use, lifestyles and governance mechanisms to ensure DLS are attained swiftly within planetary boundaries.

Methods

Below, we provide a methodological summary and refer readers to Supplementary Information sections 1.1–1.5 for details.

System definition

We combine three state-of-the-art models to quantify achievements and gaps in DLS based on available data on service inequalities[2,14], material intensities for DLS drawing on bottom-up LCA[30] and economy-wide material stocks and net additions to these drawing on top-down material use statistics[8]. We align the system boundaries of these models to calculate (Fig. 1): first, the existing material stocks providing DLS, as well as additional stocks required to close DLS stock gaps for 175 countries in the year 2015; second, the existing material stocks delivering beyond-DLS services (that is, use of service or product levels higher than DLS or outside of the DLS consumption basket) for 175 countries aggregated to 11 world regions[2] for the year 2015; and third, the new construction (net additions to stocks) required to close DLS gaps, including by when this could be achieved based on historic stock expansion rates for the period 2005–2016[8]. Prospective closure of DLS stock gaps considers the gaps in the year 2015 only, thus not accounting for future population growth.

For materials, our investigation covers all major bulk materials and economy-wide product groups but excludes aggregates in foundations of roads and civil engineering in economy-wide stocks due to high uncertainty[8] (Supplementary Tables 2 and 3). We present materials either as aggregate total or for four major material groups distinguished in economy-wide material flow accounting (biomass, fossils, metals and minerals)[42]. For products, we present product groups either as aggregate total or for seven groups—residential buildings, non-residential buildings, civil engineering, road and rail, transport vehicles, machinery and other (textiles, lamps, printed matter, furniture and products not elsewhere specified). For material flow analysis indicators (Fig. 1), we apply material flow analysis indicators 'material stocks' and 'net additions to stocks'. Material stocks are the engineered materials (for example, steel, concrete and timber) accumulated in long-lived products such as buildings, roads, other infrastructure, machinery and durable consumer products[16,17]. We partition existing economy-wide material stocks into existing material stocks that provide DLS versus beyond-DLS services (existing DLS versus beyond-DLS material stocks). Net additions to stocks are the net additions of engineered materials in final products which remain in-use as material stocks for the duration of their lifetimes. Net stock additions are calculated as gross material additions to stocks less end-of-life outflows from obsolete stocks thus representing the yearly (or multiple-year) changes in material stock levels. Net stock additions have been used to describe the speed of material stock buildup in several works[43]. Using the net stock additions indicator assumes that only new construction is used to build DLS stocks, judging it unlikely, that maintenance flows contained in gross additions to stocks would be diverted to construct DLS stocks. For options closing DLS stock gap, we consider that the DLS stock gap can be filled either by new construction of material stocks (during which both DLS and beyond-DLS stock construction can occur, see 'Material stock additions for closing DLS gaps' section for details) or by repurposing and redistribution of beyond-DLS stocks (Fig. 1). The size of the stock requirements to provide DLS can vary depending on the assumed practices and material efficiencies in countries (see 'Existing DLS material stocks and gaps' section for details).

Additional details are described in Supplementary Information section 1.1.

Existing DLS material stocks and gaps

Here, we present estimates of the material stocks providing DLS based on indicators of DLS thresholds and gaps from Kikstra et al.[2,14] and material intensities from Veléz-Henao et al.[2,14,30].

Kikstra et al.[2] estimate the country-specific service thresholds to reach DLS for each needs-dimension guided by previous research[2,9,11]. They calculate country-level service gaps (the additional service that would need to be provided to lift all those that are currently deprived up to DLS) in 2015 based on various data sources for different countries, accounting for within-country inequality, for instance considering access to sufficient space and durable construction for shelter. The data used here include minor updates described in the supplementary information of Kikstra et al.[14]. For needs-dimensions with expected large impact on results, we specified service demand by product and regional practices ('routinized type(s) of behaviour')[32], using the following data to depict practices in 2015. For nutrition, we used country-level diet shares[44] estimating the demand of different foods. For buildings to provide shelter, health and education, we used regional building archetype shares[45]. For education, we used country estimates of school going population shares to determine school-building floorspace demand[2,46]. For mobility, we used regional modal shares and occupancy rates from the IMAGE model[47,48] with additional two- and three-wheeler estimates provided by Kikstra et al.[14].

We defined average per-capita service thresholds and gaps in relation to countries' entire population, not only relating to the deprived part of the population (equation (1), service s and country c, and X is a placeholder that signifies 'threshold' or 'gap')

$$\mathrm{DLS\_service\_}X\mathrm{\_}pC_{s,c} = \frac{\mathrm{DLS\_service\_}X\mathrm{\_at\_scale}_{s,c}}{\mathrm{entire\_population}_c} \quad (1)$$

While average per-capita DLS gaps do not reflect the share of the population actually affected by DLS deprivation, they indicate the magnitude of DLS deprivation in a country and permit comparing the overall material stock requirements to close DLS gaps across countries.

Veléz-Henao and Pauliuk[30] estimate the material stock intensities of DLS services using LCA and the database ecoinvent 3.8 (ref. 49), considering the lifetime of stocks in five steps: (1) calculate the total amount of materials and services required to provide one DLS product or service unit. (2) Filter the materials and services to account only those that are classified as stocks. (3) Multiply the resulting list of materials and services related to stocks by their respective lifetime as ecoinvent reports stock-building material use as annual flows. (4) Calculate the upstream materials required to provide these stocks. (5) Filter the resulting list of materials to account only for targeted stock-building materials (Supplementary Information section 1.1). In our study, we used global LCA process data of current technology, except for the production of electricity, construction materials and cars, for which we used regional data on upstream material stock requirements, which we updated from Veléz-Henao and Pauliuk[30]. As an exception from LCA-based data, we used material intensities for five world regions from Haberl et al.[31] to estimate the material stocks contained in residential, educational and health care buildings.

For Fig. 2, we first estimated the material requirements for complete fulfilment of DLS stocks per capita (DLS stock threshold) by multiplying per-capita DLS service thresholds with material stock intensities of services (by DLS service s, practice j, country c, region r, product group p and material m; equation (2)):

$$\begin{aligned}&\mathrm{DLS\_stock\_threshold\_}pC_{s,j,c,p,m}\\&= \mathrm{DLS\_service\_threshold\_}pC_{s,c} \times \mathrm{material\_stock\_intensity}_{s,j,c,p,m}\end{aligned} \quad (2)$$

For this, we assumed the current national/regional practices (dimension j) in 2015 as default and additionally evaluate globally converged practices for housing (assuming the median of current household sizes), for mobility (assuming modal shares from the IEA Beyond 2 °C scenario[50] and the median of current vehicle occupancy) and for nutrition (assuming healthy diets with low meat consumption)[30,51]. In addition, we calculated per-capita DLS stock thresholds assuming further changes in practices (household size: minimum and maximum observed for 2015, transport modes: low car and low demand, diets: vegetarian and vegan) and material efficiency measures (100% renewable energy, electric vehicles, light weighting and material substitution in buildings) to evaluate changes to DLS stock thresholds (see Supplementary Information section 1.4 for details).

Second, we estimated the currently existing DLS material stocks per capita by multiplying current levels of DLS service provision and practices estimated for 2015 (expressed as the per-capita average over a country's entire population, equation (3)) with material stock intensities, assuming current technologies and practices (equation (4)):

$$\begin{aligned}&\mathrm{DLS\_service\_existing\_}pC_{s,c}\\&= \mathrm{DLS\_service\_threshold\_}pC_{s,c} - \mathrm{DLS\_service\_gap\_}pC_{s,c}\end{aligned} \quad (3)$$

$$\begin{aligned}&\mathrm{DLS\_stock\_existing\_}pC_{s,j,c,p,m}\\&= \mathrm{DLS\_services\_existing\_}pC_{s,c} \times \mathrm{material\_stock\_intensity}_{s,j,c,p,m}\end{aligned} \quad (4)$$

Third, we calculated the average per-capita DLS stock gaps by subtracting the currently existing DLS material stocks from the DLS stock thresholds required for full fulfilment of DLS (equation (5)). To calculate an aggregate total of DLS stocks or a total per DLS dimension, we summed DLS stocks over the respective service, practice, product and material dimensions (equation (6), where X is a placeholder for existing, threshold and gap, respectively).

$$\begin{aligned}&\text{DLS\_stock\_gap\_}pC_{s,j,c,p,m}\\&=\text{DLS\_stock\_threshold\_}pC_{s,j,c,p,m}-\text{DLS\_stock\_existing\_}pC_{s,j,c,p,m}\end{aligned} \quad (5)$$

$$\text{DLS\_stock\_}X\text{\_}pC_c=\sum_{s,j,p,m}\text{DLS\_stock\_}X\text{\_}pC_{s,j,c,p,m} \quad (6)$$

For Fig. 2a (map), we divided countries' currently existing DLS material stocks (as total, summed over all services, products and materials; equation (4) by the DLS stock thresholds required for full fulfilment of DLS assuming current national/regional practices (equation (2) and see the figure in Supplementary Information section 2.2 for four material groups). For Fig. 2a (bars), we aggregated the country-level estimates of existing DLS stocks and DLS stock gaps (both assuming current and converged of practices) to 11 world regions based on the countries-to-regions mapping from Kikstra et al.[2] (Supplementary Table 1). For Fig. 2b, we calculated the DLS stock totals (summed over all services, products and materials; equation (6)) for existing per-capita DLS material stocks and gaps per world region and country variation (median, minimum and maximum) within those. For Fig. 2c, we calculated the difference of existing DLS stocks and gaps per capita (from Fig. 2b, current practices, together summing to DLS stock thresholds) to existing economy-wide material stocks per world region reflecting all uses in the economy (as total, summed over all products and materials) and their country variation (median, minimum and maximum).

Multiplication with the population[52] yields at scale DLS stocks from per-capita values for Fig. 3a for both stock thresholds and gaps (equation (7), where X is a placeholder for existing, threshold and gap, respectively).

$$\text{DLS\_stock\_}X_{s,c,p,m}=\text{DLS\_stock\_}X\text{\_}pC_{s,c,p,m}\times\text{population}_c \quad (7)$$

Economy-wide and beyond-DLS material stocks

Here, we estimate the material stocks that meet demands beyond-DLS for 11 world regions in 2015 for Fig. 2 (beyond-DLS material stocks). Therefore, we subtracted the estimate of existing DLS material stocks from the estimate of existing economy-wide material stocks (both by product and material group in 2015). Figure 3a shows beyond-DLS stocks at scale for the globe (equation (8), summed over world regions r), whereas Fig. 3b obtains average per-capita values for world regions by dividing by the respective population sizes

$$\begin{aligned}&\text{Beyond\_DLS\_stocks\_existing}_{r,p,m}\\&=\text{economy\_wide\_stocks\_existing}_{r,p,m}-\text{DLS\_stock\_existing}_{r,p,m}\end{aligned} \quad (8)$$

For economy-wide material stocks, we used estimates from a novel database, covering 14 product groups and 21 materials[8]. Due to uncertainties in the combined estimates, the existing DLS material stocks for some material–product–region combinations were larger than estimated economy-wide material stocks, their subtraction yielding negatives (4 out of 44 data points or 0.4% negatives in terms of mass for region–material combinations—product groups aggregated, 14/77 or 1.5% negatives in terms of mass for region–product and 83/308 or 2.4% in terms of mass for region–product–material combinations). These uncertainties are a major research frontier in the field of industrial ecology[53], which we cannot resolve here. Therefore, we set any negative beyond-DLS stocks to zero and discuss the minor repercussions of this correction in the 'Limitations' section and Supplementary Information section 1.5.2.

Material stock additions for closing DLS gaps

Here, we estimate the net additions to stock required for closing DLS gaps for Fig. 3. Using net stock additions considers new stock construction only, neither including replacement of stocks at the end of their lifetime nor maintenance flows. We developed four explorative scenarios, three of which assume closure of DLS gaps entirely by new construction and one exploring the potential for a hypothetical repurposing and redistribution of stocks (Table 1).

- Figure 3 scenario (i)—build DLS stocks only assumes that only material stocks which provide DLS are built during closure of DLS gaps (corresponding to equation five, DLS stock gap). We calculated the net stock additions required for this for both current national/regional and converged practices ('Existing DLS material stocks and gaps' section).
- Figure 3 scenario (ii)—build some beyond-DLS stocks accounts for the possibility that the buildup of DLS material stocks occurs as part of economy-wide development, which includes the construction of beyond-DLS material stocks. We assumed that the construction of beyond-DLS stocks persists according to the ratios of beyond-DLS and DLS material stocks observed for world regions in the past and manifested in 2015 (Fig. 3b and equation (9)). To estimate the additions of beyond-DLS which accompany buildup of DLS material stocks, we multiplied these ratios with the DLS stock gap per region and material group (equation (10) and Supplementary Information section 1.3.4). Due to the different sizes of the DLS stock gap for current and converged practices (j), the net stock additions for these two cases differ also for scenario (ii) (Fig. 3 only shows j= current practices, for simplicity; bDLS, beyond-DLS).

$$\text{Ratio\_bDLS\_DLS}_{r,m}=\frac{\text{existing\_beyond\_DLS\_stocks}_{r,m,2015}}{\text{existing\_DLS\_stocks}_{r,m,2015}} \quad (9)$$

$$\begin{aligned}&\text{bDLS\_additions\_scenario\_ii}_{r,j,m}\\&=\text{ratio\_bDLS\_DLS}_{r,m}\times\text{DLS\_stock\_gap}_{r,j,m}\end{aligned} \quad (10)$$

- Fig. 3 scenario (iii)—build many beyond-DLS stocks assumes that constructing new DLS stocks is accompanied by extensive buildup of beyond-DLS material stocks. In this scenario, all countries are assumed to reach at least the average economy-wide material stock levels found in countries currently achieving over 95% DLS fulfilment—estimated at 177 tons per capita.

  We derived these economy-wide stock requirements based on cross-sectional regressions of per-capita economy-wide material stocks in 2015 (by four material groups, based on Wiedenhofer et al.[8]) against a country-level index of the DLS achievement in 2015 based on Kikstra et al.[2]. We calculated this index as the mean over the relative fulfilment of eighteen individual DLS indicators as done in Kikstra et al.[2]. We applied a logistic saturation function bounded between 0% and 100% DLS fulfilment, based on other studies which investigate relationships of well-being and resource use[54,55]. Based on the regression, we defined the economy-wide material stock requirements to reach DLS for all as the material stock level at which the logistic curve reaches 95% fulfilment. This threshold reflects the observation that some basic needs indicators are fulfilled by less than 100% even in the world's wealthiest nations[56–58]. The estimated economy-wide stock requirements of 177 tons per capita comprise 4.3 tons per capita of biomass, 1.2 tons per capita of fossil-based, 7.2 tons per capita of metals and 164.7 tons per capita of non-metallic mineral materials (Supplementary Information section 1.3.4).

  To calculate the beyond-DLS stock requirements additional to scenarios (i) and (ii), we subtracted the sum of existing economy-wide stocks and new stocks added in scenarios (i) and (ii) from the estimated 177 tons per capita, disaggregated by material group (equation (11)). In cases where this subtraction yielded a negative value—that is, countries already exceeding the estimated requirement—we assumed no further stock additions under scenario (iii) (Supplementary Information section 1.3.4).

$$\begin{aligned}&\text{Add\_bDLS\_additions\_scenario\_iii}_{r,m}\\&=\max([\text{ew\_stock\_requirements\_scenario\_iii}_{m}\\&-\text{economy\_wide\_stocks\_existing}_{r,p,m}-\text{DLS\_stock\_gap}_{r,j,m}\\&-\text{bDLS\_requirement\_scenario\_ii}_{r,j,m}],0)\end{aligned}\qquad(11)$$

- Scenario (r)—repurpose and redistribute explores the possibility of repurposing and redistributing material stocks within regions. We estimated which share of the regional DLS material stock gaps (Fig. 3b) could be closed by redistributing beyond-DLS stocks within these regions. Therefore, we divided the exiting beyond-DLS material stocks of a particular product group (for example, total mass of residential buildings catering to demand beyond DLS in 2015) by the DLS material stock gap of the same product group within each region (equation (12), term in brackets). We aggregated to the total share of the DLS stock gap that can be closed by repurposing and redistributing across all product groups by weighting each group's repurposing potential (equation (12), term in brackets) by its contribution to the overall DLS stock gap (product group share on DLS gap).

$$\begin{aligned}&\text{DLS\_gap\_closed\_redistr}[\%]\\&=\sum_{p}\min\left(\frac{\text{bDLS\_stocks}_{r,p}}{\text{DLS\_stock\_gap}_{r,j,p}},1\right)\times\text{product\_share\_DLS\_gap}_{r,j,p}\end{aligned}\qquad(12)$$

To communicate the size-relations between DLS gap and existing beyond-DLS stocks, Fig. 4 additionally shows the proportions of the two uses by product group (equations (13) and (14))

$$\text{Proportion\_existing\_bDLS\_stock}_{r,j,p}=\frac{\text{bDLS\_stocks}_{r,p}}{(\text{DLS\_stock\_gap}_{r,j,p}+\text{bDLS\_stocks}_{r,p})}\qquad(13)$$

$$\text{Proportion\_DLS\_stock\_gap}_{r,j,p}=1-\text{proportion\_bDLS\_stock}_{r,j,p}\qquad(14)$$

Timing of closing DLS material stock gaps

Here, we estimate in which year DLS stock gaps (for the population in 2015) could be closed when following past trajectories of stock expansion for Fig. 5. Therefore, we linearly extrapolated past regional speeds of new construction from 2005–2016 up to 2050 (except for centrally planned Asia, for which we adopted the likely trajectory of −1% per year for China as the by far largest country in this region[59]). We only considered speed of new construction because it appears unlikely that materials for maintaining existing stocks are diverted to construct DLS stocks. Speed of new construction is measured in terms of net additions to stocks from Wiedenhofer et al.[8], which we used per capita and world region, as well as global population-weighted average (Fig. 5a,b). Overall, our prospective analysis only determines the amount of new stock construction required to close DLS gaps but not the material flows required to replace or maintain stocks. The latter would require a dynamic stock-flow model and information on the age structure of all material stocks, which is not available.

We evaluated six scenario combinations of the size of the stock gap and construction speed to evaluate the progression in DLS stock achievement (Fig. 5c and equation (15)). For size of the stock gap, we assumed the scenarios (i)–(iii) presented in methods section four. For construction speed, we assumed, first, the extrapolation of past regional per-capita speed for each world region (Fig. 5c, dashed lines), and second, the extrapolation of past global average speed per capita for all world regions (Fig. 5c, solid lines).

$$\Delta\text{DLS\_stock\_reached}_{r,m,t}=\frac{\sum_{2016}^{t}\text{construction\_speed}_{r,m,t}}{\text{stock\_gap\_size\_scenarios}_{r,j,m}}\qquad(15)$$

In Fig. 5c, we present results for the globe by aggregating regional achievement of DLS through calculating the population-weighted average of achievement across world regions. We did not assess speed for the scenario (r), repurpose and redistribute, as this scenario hinges on political and socio-economic factors rather than biophysical ones, which are not focus of this work.

Sensitivity analysis

We tested the sensitivity of our main results to variations in DLS service threshold indicators (±25%), lifetime assumptions for modelling economy-wide material stocks (±30%) and using another material intensity dataset for residential buildings as the largest product group in DLS stock estimates[45]. The DLS service thresholds and material intensities influence our estimates of the material stocks required to fully provide DLS (and the estimated stock gap) in the first two results sections. The lifetimes influence our estimates of past speed of new construction (net stock additions, through determining the amount of maintenance activities in overall construction) (Supplementary Information section 1.1), and thereby, the scenarios of future construction speeds that codetermine how fast DLS gaps can be closed in the last results section.

Limitations

Below, we provide an extended summary of limitations. See Supplementary Information section 1.5 for more details.

Limitations in calculating DLS material stocks by combining DLS indicators with material intensities. First, DLS indicators were only available for 2015 and information to calculate DLS gaps is scarce and needs to be improved. Second, some DLS indicators are not ideal for integration with material intensities, as they, for instance, refer to monetary expenditures on education and health[2]. Third, the consumption basket of DLS in our study is not comprehensive, as, for instance, for education/health, it only takes into account the building itself but not what is in there in terms of equipment. Fourth, material intensities from the LCA need further refinement. Currently, they are built on simple down-scaling of provisioning systems in specific countries (often Switzerland), which may bias results towards the patterns seen in high-income countries. Material intensities may also be incomplete due to truncation errors in the supply chain of services[41]. Another limitation is the use of average stock requirements to model the expansion of service provision, which can bias stock needs in particular for shared infrastructure such as roads and rails. A core infrastructure network is needed to enable reaching important destinations—even if only for a single user—but additional users may require minimal extension. Capturing this distinction of average and marginal infrastructure needs can be covered by time-explicit scenarios based on Integrated Assessment Models (IAMs). Fifth, material intensities for buildings need improvement due to lacking country-level resolution on climate zone and construction-type variability[53]. Sixth, information on technologies and lifestyles are only available at coarse resolution (often world regions)[31,49]. Seventh, to assess pathways for closing DLS gaps, we considered the two main cases of current and converged global practices ('Existing DLS material stocks and gaps' section), along with selected additional changes in practices and material efficiency. Further changes in, for example, urban form or adoption of low-carbon materials, could enable substantial decoupling of DLS provision from raw material use and GHG emissions and should be assessed in future work.

Limitations in calculating demands for DLS versus beyond-DLS. First, in some cases, the bottom-up estimates of existing DLS material stocks were larger than the top-down estimates of economy-wide material stocks, leading to negative beyond-DLS stocks ('Economy-wide and beyond-DLS material stocks' section). We set these negatives to zero stocks (small bias as negatives between 0.4–2.4% of total beyond-DLS stocks). This step does not 'delete' any material stocks but simply affects the allocation of stocks to either DLS or beyond-DLS stocks, thus resulting in either overestimated DLS material stocks or underestimated beyond-DLS. The consistent combination of bottom-up and top-down methods is an ongoing research endeavour in the field of industrial ecology[53], which we cannot solve here. Second, integrating the two data sources combines a consumption-based (DLS) with a production-based (economy-wide) perspective. When calculating domestic beyond-DLS stocks by subtracting consumption-based DLS stocks from production-based economy-wide stocks, some stocks labelled as domestic within a specific country might actually either be located in other regions or cater towards exports and not contribute to domestic consumption. To mitigate this issue, we calculated beyond-DLS stocks for world regions only, for which we assumed all trade happening within regions. Third, the current data do not permit unequivocal interpretation of the calculated beyond-material stocks as providing only beyond-DLS services: the beyond-DLS stocks are overestimated if DLS material stocks are underestimated, for example, when DLS provision in reality requires more materials than estimated via the material intensities based on Veléz-Henao and Pauliuk[30] or if the consumption basket is not comprehensive, such as missing equipment in buildings discussed above.

Limitations in calculating material stock additions required for and timing of closing DLS gaps. First, our scenarios are stylized and explorative, only roughly indicating potentials for the resource-efficient and timely closing of DLS gaps. While scenario (i) is a detailed assessment of the material stock gap, scenarios (ii) and (iii) assume that the observed regional/global ratios of DLS and beyond-DLS persist in the future, and scenario (r) assumes a match of supply and demand between the DLS gap and available beyond-DLS stocks geospatially, as well as regarding the interchangeability of product groups. In addition, we estimated gap closure based on past speeds of new construction and either based on a stock total (summed over all materials) or four material groups, assuming substitutability between materials in the total or groups. In reality, feasibilities depend on various biophysical, social and political constraints.

Reporting summary

Further information on research design is available in the Nature Portfolio Reporting Summary linked to this article.

Data availability

The descriptive and results data are presented in the Supplementary Information. The input data to reproduce results are available via GitHub at https://github.com/socialecologyboku/DLSmaterialStocks.

Code availability

The code to reproduce results is available via GitHub at https://github.com/socialecologyboku/DLSmaterialStocks.

References

1. UN DESA. *Sustainabile Development Goals Report 2022* (United Nations, 2022).
2. Kikstra, J. S. et al. Decent living gaps and energy needs around the world. *Environ. Res. Lett.* **16**, 95006 (2021).
3. UN Environment. *Global Environment Outlook—GEO-6* (Cambridge Univ. Press, 2019).
4. United Nations Environment Programme International Resource Panel. *Global Resources Outlook 2024: Bend the Trend—Pathways to a Liveable Planet as Resource Use Spikes* (UNEP, 2024).
5. Wiedmann, T. et al. Scientists' warning on affluence. *Nat. Commun.* **11**, 3107 (2020).
6. Rammelt, C. F. et al. Impacts of meeting minimum access on critical earth systems amidst the Great Inequality. *Nat. Sustain.* **6**, 212–221 (2023).
7. Zhou, Y. et al. Satellite mapping of urban built-up heights reveals extreme infrastructure gaps and inequalities in the Global South. *Proc. Natl Acad. Sci. USA* **119**, e2214813119 (2022).
8. Wiedenhofer, D. et al. From extraction to end-uses and waste management: modeling economy-wide material cycles and stock dynamics around the world. *J. Ind. Ecol.* **28**, 1464–1480 (2024).
9. Rao, N. D. & Min, J. Decent living standards: material prerequisites for human wellbeing. *Soc. Indic. Res.* **138**, 225–244 (2018).
10. Sahakian, M. et al. Advancing the concept of consumption corridors and exploring its implications. *Sustain. Sci. Pract. Policy* **17**, 305–315 (2021).
11. Rao, N. D., Min, J. & Mastrucci, A. Energy requirements for decent living in India, Brazil and South Africa. *Nat. Energy* **14**, 190 (2019).
12. Millward-Hopkins, J. et al. Providing decent living with minimum energy: a global scenario. *Glob. Environ. Change* **65**, 102168 (2020).
13. Huo, J. et al. Achieving decent living standards in emerging economies challenges national mitigation goals for CO_2 emissions. *Nat. Commun.* **14**, 6342 (2023).
14. Kikstra, J. S. et al. Closing decent living gaps in energy and emissions scenarios: introducing DESIRE. *Environ. Res. Lett.* **20**, 54038 (2025).
15. Crippa, M. et al. *CO_2 Emissions of All World Countries—2022 Report* (Publications Office of the European Union, 2022); https://edgar.jrc.ec.europa.eu/report_2022
16. Lanau, M. et al. Taking stock of built environment stock studies: progress and prospects. *Environ. Sci. Technol.* **53**, 8499–8515 (2019).
17. Deng, T., Zhang, Y. & Fu, C. Modelling dynamic interactions between material flow and stock: a review of dynamic material flow analysis. *Ecol. Indic.* **156**, 111098 (2023).
18. Thacker, S. et al. Infrastructure for sustainable development. *Nat. Sustain.* **2**, 324–331 (2019).
19. Tanikawa, H. et al. A framework of indicators for associating material stocks and flows to service provisioning: Application for Japan 1990–2015. *J. Clean. Prod.* **285**, 125450 (2021).
20. Krausmann, F. et al. Global socioeconomic material stocks rise 23-fold over the 20th century and require half of annual resource use. *Proc. Natl Acad. Sci.* **114**, 1880–1885 (2017).
21. Krausmann, F., Wiedenhofer, D. & Haberl, H. Growing stocks of buildings, infrastructures and machinery as key challenge for compliance with climate targets. *Glob. Environ. Change* **61**, 102034 (2020).
22. Hertwich, E. G. Increased carbon footprint of materials production driven by rise in investments. *Nat. Geosci.* **44**, 1888 (2021).
23. Lamb, W. F. et al. A review of trends and drivers of greenhouse gas emissions by sector from 1990 to 2018. *Environ. Res. Lett.* **16**, 73005 (2021).
24. Haberl, H. et al. Social metabolism and biodiversity. In *Encyclopedia of Biodiversity* (ed. Scheiner, S. M.) 526–542 (Elsevier, 2024).
25. Luckeneder, S. et al. Surge in global metal mining threatens vulnerable ecosystems. *Glob. Environ. Change* **69**, 102303 (2021).

26. Pauliuk, S. & Müller, D. B. The role of in-use stocks in the social metabolism and in climate change mitigation. *Glob. Environ. Change* **24**, 132–142 (2014).
27. Seto, K. C. et al. Carbon lock-in: types, causes, and policy implications. *Annu. Rev. Environ. Resour.* **41**, 425–452 (2016).
28. Haberl, H. et al. The material stock–flow–service nexus: a new approach for tackling the decoupling conundrum. *Sustainability* **9**, 1049 (2017).
29. Müller, D. B. et al. Carbon emissions of infrastructure development. *Environ. Sci. Technol.* **47**, 11739–11746 (2013).
30. Vélez-Henao, J. A. & Pauliuk, S. Material requirements of decent living standards. *Environ. Sci. Technol.* **57**, 14206–14217 (2023).
31. Haberl, H. et al. Weighing the global built environment: high-resolution mapping and quantification of material stocks in buildings. *J. Ind. Ecol.* **29**, jiec.13585 (2024).
32. Reckwitz, A. Toward a theory of social practices. *Eur. J. Soc. Theory* **5**, 243–263 (2002).
33. Lamb, W. F. et al. Transitions in pathways of human development and carbon emissions. *Environ. Res. Lett.* **9**, 14011 (2014).
34. Hou, L. et al. A comprehensive accounting of construction materials in belt and road initiative projects. *Environ. Sci. Technol.* **58**, 15575–15586 (2024).
35. Andrijevic, M. et al. Governance in socioeconomic pathways and its role for future adaptive capacity. *Nat. Sustain.* **3**, 35–41 (2020).
36. Bertram, C. et al. Feasibility of peak temperature targets in light of institutional constraints. *Nat. Clim. Change* **14**, 954–960 (2024).
37. Millward-Hopkins, J. Inequality can double the energy required to secure universal decent living. *Nat. Commun.* **13**, 5028 (2022).
38. Soergel, B. et al. Multiple pathways towards sustainable development goals and climate targets. *Environ. Res. Lett.* **19**, 124009 (2024).
39. Dorninger, C. et al. Global patterns of ecologically unequal exchange: implications for sustainability in the 21st century. *Ecol. Econ.* **179**, 106824 (2021).
40. O'Neill, D. W. et al. A good life for all within planetary boundaries. *Nat. Sustain* **1**, 88–95 (2018).
41. Ward, H. et al. Truncation error estimates in process life cycle assessment using input–output analysis. *J. Ind. Ecol.* **22**, 1080–1091 (2018).
42. *The Use of Natural Resources in the Economy: A Global Manual on Economy-Wide Material Flow Accounting* (UNEP, 2023).
43. Fishman, T., Schandl, H. & Tanikawa, H. Stochastic analysis and forecasts of the patterns of speed, acceleration, and levels of material stock accumulation in society. *Environ. Sci. Technol.* **50**, 3729–3737 (2016).
44. Dietary composition by country: FAO Food Balances. *FAO and Our World in Data* https://ourworldindata.org/grapher/dietary-composition-by-country (2023, accessed 22 August 2024).
45. Pauliuk, S. et al. Global scenarios of resource and emission savings from material efficiency in residential buildings and cars. *Nat. Commun.* **12**, 5097 (2021).
46. "Sustainable Development Goals 1 and 4." *UNESCO Institute for Statistics* https://uis.unesco.org/ (2023, accessed 8 July 2023).
47. van Vuuren, D. et al. *The 2021 SSP scenarios of the IMAGE 3.2 model 2021*. The Hague: PBL Netherlands Environmental Assessment Agency (2021); https://www.pbl.nl/sites/default/files/downloads/pbl-2021-the-2021-ssp-scenarios-of-the-image-3-2-model_4740.pdf
48. Edelenbosch, O. Y. et al. Transport fuel demand responses to fuel price and income projections: Comparison of integrated assessment models. *Transport. Res. Part D* **55**, 310–321 (2017).
49. Wernet, G. et al. The ecoinvent database version 3 (part I): overview and methodology. *Int. J. Life Cycle Assess.* **21**, 1218–1230 (2016).
50. *Energy Technology Perspectives (ETP)—Catalysing Energy Technology Transformations 2017* (IEA, 2017); https://www.iea.org/reports/etp-model-2017
51. Springmann, M. et al. Analysis and valuation of the health and climate change cobenefits of dietary change. *Proc. Natl Acad. Sci. USA* **113**, 4146–4151 (2016).
52. *World Population Prospects 2019, Online Edition. Rev. 1* (UN DESA Population Division, 2019); https://population.un.org/wpp/
53. Streeck, J. et al. Quantifying material stocks in long-lived products: challenges and improvements for informing sustainable resource use strategies. *Resour. Conserv. Recycl.* **221**, 108324 (2025).
54. Steinberger, J. K. & Roberts, J. T. From constraint to sufficiency: the decoupling of energy and carbon from human needs, 1975–2005. *Ecol. Econ.* **70**, 425–433 (2010).
55. Lamb, W. F. & Rao, N. D. Human development in a climate-constrained world: what the past says about the future. *Glob. Environ. Change* **33**, 14–22 (2015).
56. Fisch-Romito, V. Embodied carbon dioxide emissions to provide high access levels to basic infrastructure around the world. *Glob. Environ. Change* **70**, 102362 (2021).
57. Lamb, W. F. Which countries avoid carbon-intensive development? *J. Clean. Prod.* **131**, 523–533 (2016).
58. Rao, N. D., Riahi, K. & Grubler, A. Climate impacts of poverty eradication. *Nat. Clim. Change* **4**, 749–751 (2014).
59. Wiedenhofer, D. et al. Prospects for a saturation of humanity's resource use? An analysis of material stocks and flows in nine world regions from 1900 to 2035. *Glob. Environ. Change* **71**, 102410 (2021).

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Author contributions

J.S.: conceptualization, methodology, software, validation, formal analysis, investigation, data curation, visualization, writing—original draft and funding acquisition. J.A.V.-H.: conceptualization, methodology, software, validation, formal analysis, investigation, data curation and writing—review and editing. J.S.K.: conceptualization, methodology, software, validation, formal analysis, data curation, visualization and writing—review and editing. S.P.: conceptualization and writing—review and editing. J.M.: conceptualization, methodology and writing—review and editing. F.K.: conceptualization and writing—review and editing. H.H.: conceptualization, writing—review and editing and funding acquisition. S.P.: methodology and writing—review and editing. T.Z.: software, data curation, visualization and writing—review and editing. D.W.: conceptualization, methodology, writing—review and editing, project administration and funding acquisition.

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Competing interests
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Extended Data Table 1 | Results of monovarietal sensitivity analysis

	Default (current national/regional practices)	DLS threshold -25%	DLS threshold +25%	Residential building MIs from (Pauliuk et al. 2021).	Economy-wide stock lifetimes -30%	Economy-wide stock lifetimes +30%
Figure 2						
Share of DLS stocks reached						
Global North (min-max, median)	**50%-100% (95%)**	55%-100% (97%)	46%-100% (94%)	51-100% (95%)	no changes	no changes
Global South (min-max, median)	**19%-92% (59%)**	21-93% (62%)	17%-91% (57%)	19-91% (60%)	no changes	no changes
Centrally Planned Asia (min-max, median)	**56%-73% (63%)**	58%-77% (65%)	54%-71% (61%)	59%-74% (64%)	no changes	no changes
DLS stock gap, global (Gigatons)	**82.2**	57.4	108.5	74.6	no changes	no changes
DLS stock thresholds (tons/cap)						
Global average	**37.6**	28.6	46.5	34.0	no changes	no changes
Sub-Saharan Africa	**33.9**	25.8	42.1	32.4	no changes	no changes
Centrally Planned Asia	**49.8**	37.9	61.7	35.9	no changes	no changes
Eastern Europe	**49.1**	37.7	60.5	45.4	no changes	no changes
Former Soviet Union	**41.6**	31.7	51.6	37.0	no changes	no changes
Latin America	**35.7**	27.2	44.3	31.2	no changes	no changes
Middle East & North Africa	**32.5**	24.7	40.3	31.3	no changes	no changes
North America	**41.5**	31.7	51.4	42.9	no changes	no changes
Japan, Australia, New Zealand	**41.0**	31.3	50.7	38.0	no changes	no changes
Pacific Asia	**29.6**	22.6	36.6	32.7	no changes	no changes
South Asia	**28.5**	21.8	35.3	29.6	no changes	no changes
Western Europe	**45.6**	34.9	56.2	41.6	no changes	no changes
Country maximum	**63.3**	48.7	78.0	59.2	no changes	no changes
Country minimum	**26.4**	20.2	32.7	26.9	no changes	no changes
Figure 3						
Share DLS stocks on economy-wide stocks						
Global	**27%**	22%	33%	25%	30%	26%
Sub-Saharan Africa	**62%**	52%	69%	60%	65%	61%
Centrally Planned Asia	**22%**	18%	26%	16%	23%	21%
Eastern Europe	**26%**	20%	31%	24%	30%	24%
Former Soviet Union	**20%**	16%	24%	17%	24%	18%
Latin America	**46%**	37%	55%	40%	49%	45%
Middle East & North Africa	**24%**	19%	29%	23%	26%	24%
North America	**22%**	17%	27%	23%	26%	20%
Japan, Australia, New Zealand	**22%**	17%	27%	21%	26%	21%
Pacific Asia	**34%**	27%	41%	38%	36%	34%
South Asia	**48%**	39%	56%	51%	52%	46%
Western Europe	**23%**	18%	28%	21%	27%	22%
Net additions to stocks required to close DLS gaps vis a vis 2015 economy-wide stocks (global)						
scenario-i	**11.6%**	8.1%	15.2%	10.5%	12.7%	11.0%
scenario-ii	**33.2%**	28.3%	37.4%	32.3%	34.1%	32.6%
scenario-iii	**98.9%**	97.1%	99.7%	97.8%	112.4%	93.4%
Share of DLS gap which could be closed by repurposing (global)						
Sub-Saharan Africa	**21%**	36%	15%	26%	17%	23%
Centrally Planned Asia	**84%**	87%	82%	77%	83%	85%

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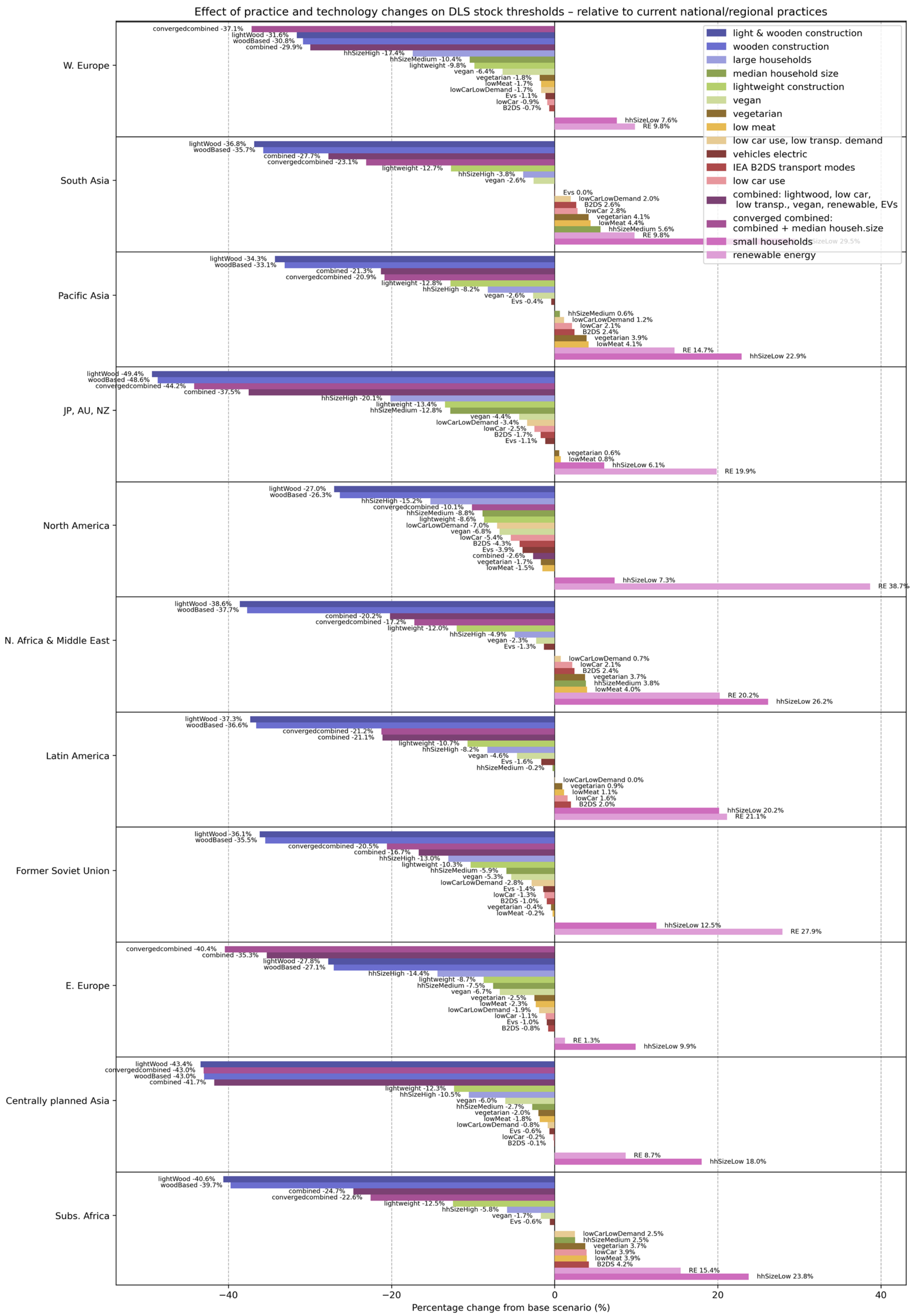
Extended Data Table 1 (continued) | Results of monovarietal sensitivity analysis

	Default (current national/regional practices)	DLS threshold -25%	DLS threshold +25%	Residential building MIs from (Pauliuk et al. 2021).	Economy-wide stock lifetimes -30%	Economy-wide stock lifetimes +30%
Eastern Europe	**97%**	100%	95%	97%	95%	100%
Former Soviet Union	**100%**	100%	100%	100%	99%	100%
Latin America	**69%**	88%	50%	71%	67%	81%
Middle East & North Africa	**94%**	95%	94%	95%	94%	95%
North America	**99%**	100%	87%	99%	90%	100%
Japan, Australia, New Zealand	**100%**	100%	100%	100%	100%	100%
Pacific Asia	**86%**	96%	78%	82%	84%	90%
South Asia	**73%**	83%	58%	64%	66%	78%
Western Europe	**100%**	100%	100%	100%	100%	100%
Figure 5						
Year when reaching 100% DLS globally						
@regional construction speed						
scenario-i	**2031**	2027	2034	2030	2031	2030
scenario-ii	**2036**	2035	~2050	2039	~2050	2037
scenario-iii	**93% DLS stock thresholds in 2050**	93% DLS stock thresholds in 2050	93% DLS stock thresholds in 2050	93% DLS stock thresholds in 2050	92% DLS stock thresholds in 2050	93% DLS stock thresholds in 2050
@global (per capita) average construction speed						
scenario-i	**2020**	2019	2021	2020	2021	2020
scenario-ii	**2027**	2026	2029	2027	2028	2027
scenario-iii	**2042**	2042	2042	2042	2044	2041

Results of monovarietal sensitivity analysis under assumption that DLS stock gaps are closed while maintaining current national/regional practices (see methods section six for details).



Extended Data Fig. 1 | Effect of practice and technology changes on DLS stock thresholds. Impact of changes in practices and technologies on DLS stock thresholds across world-regions, relative to a baseline assuming continuation of current national/regional practices. For details on the modelled changes please see SI 1.4. Underlying data are provided in the Supplementary Data 1 tab DLS_stock_thresh_efficiency (last tab).

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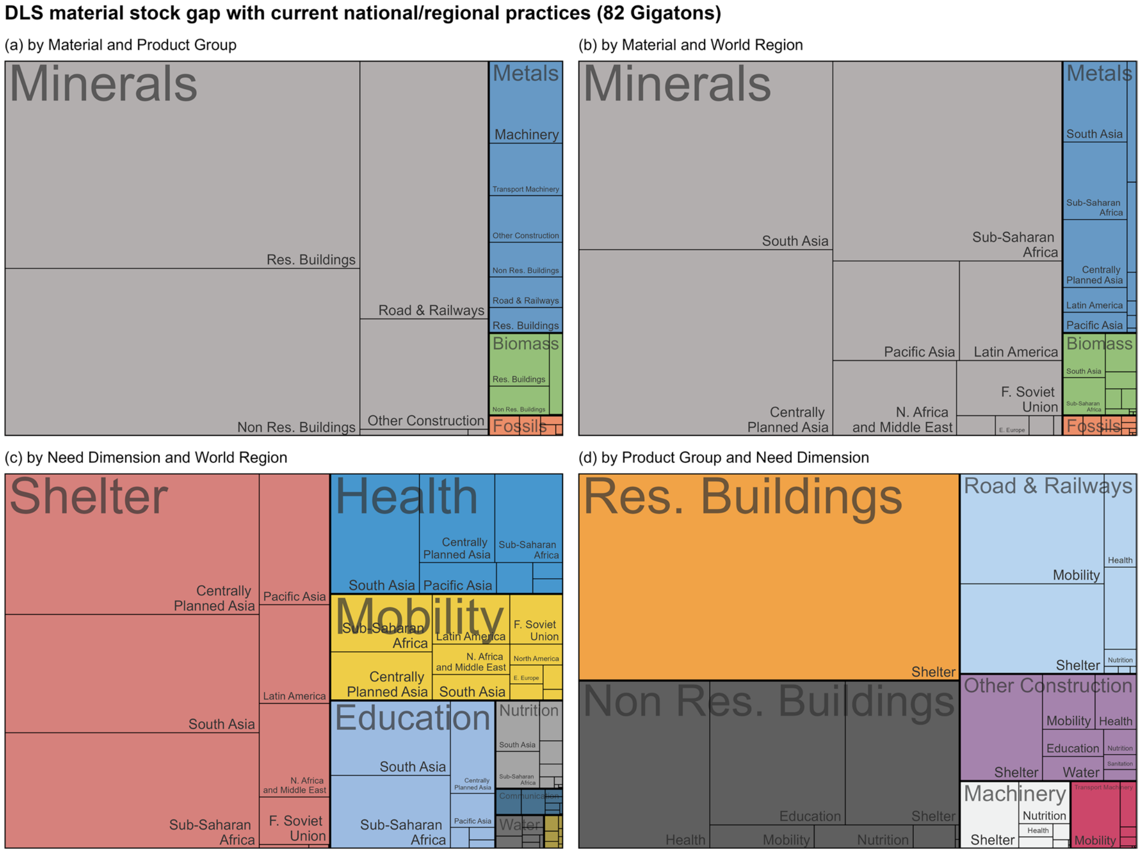

Extended Data Fig. 2 | Composition of DLS material stock gap. Decent Living Standards (DLS) material stock gap which needs to be closed to achieve DLS for all, disaggregated by material type, product group, needs dimension, and region – assuming continuation of current national/regional practices as of 2015. Data available in Supplementary Data 1 tab Fig3_stockGapCurr_RMDP.

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Our web collection on statistics for biologists contains articles on many of the points above.

Software and code

Policy information about availability of computer code

Data collection	n.a.
Data analysis	Scripts and data to reproduce all results are shared in a public Github repository: https://github.com/socialecologyboku/DLSmaterialStocks

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We built on and updated data from the studies of Kikstra et al. 2025 (10.1088/1748-9326/adc3ad), Veléz & Pauliuk 2023 (DOI: 10.1021/acs.est.3c03957) and Wiedenhofer et al. 2024 (DOI: 10.1111/jiec.13575).
The descriptive and results data supplements are available attached to the main article presentation. The input data and software scripts to reproduce all results are shared in a public Github repository: https://github.com/socialecologyboku/DLSmaterialStocks

Human research participants

Policy information about studies involving human research participants and Sex and Gender in Research.

Reporting on sex and gender	n.a.
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Recruitment	n.a.
Ethics oversight	n.a.

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Ecological, evolutionary & environmental sciences study design

All studies must disclose on these points even when the disclosure is negative.

Study description	We combined three state-of-the-art models which quantify: the achievement and gaps of decent living standards (DLS) based on available data on service inequalities, material intensities for DLS from bottom-up drawing on Life Cycle Assessment, and economy-wide material stocks and their net additions drawing on top-down statistics on material use. We aligned the system boundaries of these models to calculate: 1) the material stocks currently used to provide DLS, as well as the additional stocks required to close DLS gaps for 175 countries in the year 2015, 2) the existing material stocks delivering beyond-DLS services for 175 countries aggregated to eleven world-regions for the year 2015, and 3) the amount of new construction required to close DLS gaps, as well as the future year up to 2050 in which this could be achieved based on historic stock expansion rates for the period 2005-2016.
Research sample	Indicator data for 175 countries in 2015; data from Life Cycle Assessment which accounts for material requirements of industrial processes to supply functional units of products/services
Sampling strategy	n.a.
Data collection	We built on and updated data from the studies of Kikstra et al. 2025 (10.1088/1748-9326/adc3ad), Veléz & Pauliuk 2023 (DOI: 10.1021/acs.est.3c03957) and Wiedenhofer et al. 2024 (DOI: 10.1111/jiec.13575).
Timing and spatial scale	Data was collected during the years 2023, 2024 and 2025.
Data exclusions	n.a.
Reproducibility	The data and software to reproduce all results and figures are available in the shared repository (see above)
Randomization	n.a.
Blinding	n.a.

Did the study involve field work? ☐ Yes ☒ No

Reporting for specific materials, systems and methods

We require information from authors about some types of materials, experimental systems and methods used in many studies. Here, indicate whether each material, system or method listed is relevant to your study. If you are not sure if a list item applies to your research, read the appropriate section before selecting a response.

Materials & experimental systems

n/a	Involved in the study	
☒	☐	Antibodies
☒	☐	Eukaryotic cell lines
☒	☐	Palaeontology and archaeology
☒	☐	Animals and other organisms
☒	☐	Clinical data
☒	☐	Dual use research of concern

Methods

n/a	Involved in the study	
☒	☐	ChIP-seq
☒	☐	Flow cytometry
☒	☐	MRI-based neuroimaging