

Water, land, materials, and emissions for providing decent living standards around the world

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ABSTRACT

The safe and just space for humanity is a vision for a sustainable economy, where all people have decent access to services so that social requirements are met (floor), and the use of natural resources does not drive critical Earth system processes beyond Holocene conditions (ceiling). Using the concept of decent living standards (DLS) to quantify the resource implications of social requirements (floor) globally, we estimate the average in-use stocks, as well as associated annual natural resource use and related greenhouse gas emissions (GHG) that are required to provide a DLS in 176 countries. Our results suggest that the per capita resources and emissions associated with a DLS differ considerably between countries, depending on their socioeconomic and technological context. With renewable energies, a reduction in meat consumption and active mobility (efficient scenario), the following average per capita DLS impacts results: materials: 2–5 t/(cap*yr), GHG emissions: 1–4 t CO₂ eq./(cap*yr), land occupation: 1424–6615 m²/cap, and water use: 98–328 m³/(cap*yr). The in-use stocks in the form of materials required to provide a DLS range from 26 to 29 t/cap. Closing the current DLS gap globally in the most efficient form requires resources equivalent to 7 % of global materials use, 1 % of GHG emissions, 2 % of land occupation, and 2 % of water consumption in 2015.

1. Introduction

Eradicating poverty while keeping environmental pressures within climate budgets is one of the major endeavors of mankind. However, although major progress has been made in international commitments, e.g., the Paris Agreement (UNFCCC, 2015) and the Sustainable Development Goals (SDGs) (UN, 2017), achieving these goals seems out of reach (UN, 2024).

While some SDG indicators measure the outcomes related to pre-defined human well-being targets, they often fall short of delineating the necessary amount of resources, e.g., land, water, energy, and materials, and impacts, e.g., GHG linked to these targets (Rao and Min, 2018).

To address this issue, Rao and Min (2018) introduced the concept of Decent Living Standards (DLS), which comprises a bundle of essential services for needs-based or eudaimonic human well-being. The strength of the DLS framework is that it links the minimum service requirements for a decent life to provisioning systems to quantify resource requirements and environmental pressures and impacts, thereby

providing a more integrated approach to understanding the linkages between well-being, resource use, and environmental impact (O'Neill et al., 2018).

Existing research has been mainly focused on the energy needed to provide DLS (Millward-hopkins et al., 2020; Rao et al., 2019), which have been recently extended to CO₂ emissions (Huo et al., 2023), material footprints and stocks (Vélez-Henao and Pauliuk, 2023; Virág et al., 2022), energy, CO₂ emissions, and material stocks DLS gaps (the difference between the DLS thresholds and current deprivation levels) (Kikstra et al., 2021, 2024; Streeck et al., 2025), and linked to planetary boundaries (Kromand et al., 2025; Schlesier et al., 2024) and inequality (Millward-Hopkins, 2022; Millward-Hopkins and Oswald, 2023; Pauliuk, 2024). These contributions provide meaningful insights into the energy, CO₂ emissions, and material stocks required to eradicate poverty on a country-scale, while for materials footprints, the results are limited to a global perspective (Vélez-Henao and Pauliuk, 2023).

What is still missing are region-specific estimates of the stock-flow-service nexus (Haberl et al., 2017) for achieving DLS for all. This

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nexus assessment relates the DLS services to the required in-use stocks, the operational and build-up material and energy flows, and associated environmental pressures at the country level.

This paper addresses four questions: (1) What are the resource flows, emissions, and in-use stocks associated with the current provision of DLS at the country level? (2) What services and industries drive the DLS footprint and in-use stocks in the different countries? (3) How much resource and emissions savings can be achieved by a rapid energy transition and a change in diets and mobility preferences? (4) How much resources, emissions, and in-use stocks are required to eradicate poverty in each country?

2. Materials and methods

Our analysis focuses on the resources and emissions footprints and in-use stocks of nine DLS dimensions (from food provisioning to information and communication technologies) in 176 countries in the year 2015 (see SI2 for a list of the countries and region classification). We applied a country-specific version of the method developed by Véléz-Henao and Pauliuk (2023), i.e., a life cycle assessment (LCA) with regional detail in supply and demand, to extract the different flows and stocks from the product systems required to provide a single person with DLS in a given country. The DLS framework of Rao and Min (2018) and the DLS thresholds for nine dimensions provided by Millward-Hopkins et al. (2020) and Véléz-Henao and Pauliuk (2023) are regionalized. We calculate region-specific DLS gaps following the methodology of Kikstra et al. (2021) and several databases, e.g., FAO, ITU, and UN (see SI1), to obtain national level estimates.

The method follows four steps. (A) Compile a country-specific list of services required by each DLS and DLS gap dimension from several databases and adjusted values from Kikstra et al. (2021, 2024) (see supporting information (SI)1–2 for more details). Two types of provisioning systems are considered: flow as a service, e.g., food and electricity consumption, and stock-derived service, where an in-use stock, such as a building, infrastructure, or household appliance, is operated to provide a service to end users. (B) Estimate the reference flows (bundle of products, in-use stocks, and services) required to meet DLS requirements by region. Since some of the services are stock-based (like m² of living space) and energy-based (like MJ for thermal comfort), the reference flows for some provisioning systems need to be calculated from the stock-flow-service nexus (Haberl et al., 2017) and the energy service cascade concepts (Kalt et al., 2019), respectively (see SI1 for details). The key assumption here is that product systems are modelled assuming a stationary state of all in-use stock involved, so that the average maintenance of in-use stocks, calculated as:

$$\text{stock_maintenance_inflow} = \text{stock}/\text{lifetime}$$

is added to the throughput flows for operational energy and food products.

The single person country-specific LCA foreground systems were built using country-specific demand factors such as diets, transport modes, cooking and heating energy carriers, average yearly temperature, and income level, while for the supplying background system, we used the ecoinvent 3.8 database and the system model ‘allocation, cutoff by classification’ (Wernet et al., 2016). Where possible, we used country-specific unit processes, e.g., for electricity supply; otherwise, we use world-average technology (i.e., processes with global or rest-of-the-world geographical scope), e.g., construction materials, most food products, transport modes, and household appliances (see Table 1 for an overview, and SI1–2 for detailed information on the threshold calculations, back and foreground link, main assumptions used to model each country, and equation applied).

(C) The indirect in-use stocks in the form of industrial capital (e.g., material stocks in the steel industry that are attributed to transportation services through the steel required for the vehicles) are estimated,

Table 1

Summary of the DLS thresholds, DLS gap, the service provisioning (background from ecoinvent), and foreground (country-specific data).

DLS dimension	DLS Threshold and proxy	DLS gap range	LCA background (supply)	LCA foreground (demand)
Shelter	15 m ² /(cap) (stock)	0–13,3 m ² / (cap) (stock)	Cement, paper, wood, concrete,	Building archetypes from the RECC model
Education	1,2–4,2 m ² / (cap)(stock)	0–3,5 m ² / (cap) (stock)	steel, Bricks, Natural gas, Electricity,	based on five regions and income levels
Healthcare	1,6 m ² /(cap) (stock)	0–1,6 m ² / (cap) (stock)	Lamps	for the efficiency type.
Collective services	4,7 m ² /(cap) (stock)	0–3,5 m ² / (cap) (stock)		Electricity region- specific with proxies for 37 countries
Nutrition	1907–2327 kcal/ (cap*day) (flow)	0–581 kcal/ (cap*day) (flow)	Animal fats, Vegetable oil, Oilcrops, Sugar & sweeteners, Starchy roots, Meat sheep & goat, Meat pig, Meat poultry, Meat beef, Milk, Nuts, Fruits, Vegetables, Pulses, Cereals, others, Barley, Maize, Rice, Wheat, Electricity, Natural gas, Refrigerator, Cookstove	Country- specific population, diet composition. Cooking fuel
Hygiene	50 L water/ (cap*day) (flow) 0,46–2,21 kg waste treatment/ (cap*day) (flow)	0–7,1 L water (cap/ day)(flow) 0,46–2,21 kg waste/ (cap*day) (flow)	Natural gas, Tap water, Waste treatment (wt) open dump, wt. Open burning, wt. Unsanitary landfill, wt. Biowaste, wt. sanitary landfill, wastewater treatment	Waste quantities and shares of waste disposal type based on six global regions, average year temperature, country- specific, heating with gas
Clothing	2,4–4,8 kg clothes/ (cap*yr) (flow)	No gap assumed	Electricity, washing machine, Dryer, Woven cotton, Knit cotton, Synthetic rubber, Wool	Electricity region- specific with proxies for 37 countries, average year temperature country- specific, washing machine efficiency based on country income level, dryer for countries

(continued on next page)

Table 1 (continued)

DLS dimension	DLS Threshold and proxy	DLS gap range	LCA background (supply)	LCA foreground (demand)
Mobility	3549–15,000 pkm/(cap*yr) (flow)	0–4711 pkm/(cap*yr) (flow)	Bicycle, Electric bicycle, Motor scooter, Electric scooter, Passenger car, Electric car, Bus, Train	with average temperature < 20 country-specific modal split share and occupancy rate, the share of electric vehicles based on 35 regions
Communication	Access to information in devices/ (cap)(stock)	0–100 % of the population (stock)	Electricity, Smartphone, Laptop, Internet	Country-specific data on appliance ownership

Country and regions-specific values are provided in SI2. The LCA foreground system converts service demand into demand for generic ‘background’ products via a stationary stock-flow-service nexus.

following the approach developed by Véléz-Henao and Pauliuk (2023). (D) Estimate the resources and emissions associated with the DLS using the LCA approach.

The DLS gap is defined as the amount of additional resources and emissions necessary to lift a person below the minimum up to the DLS threshold. Thus, the country gaps are estimated as the product of the DLS gap on a per capita basis and the population of each country.

Five footprints were estimated: total material requirements (TMR) and raw material inputs (RMI) in kg/yr, global warming potential (GWP100 hereafter GWP) in kg CO₂-eq/yr, the water depletion indicator in m³/yr for water use (WU), and the agricultural land occupation indicator in m²*yr/yr (LO). For material footprints, we use the characterization factors (CFs) provided by Pauliuk (2022), while for other footprints, we use the ReCiPe2016 V1.1 CFs (Huijbregts et al., 2017), a robust and widely used approach among LCA practitioners. Because our product system does not contain any exports of other products and commodities, the RMI indicator equals the raw material consumption (RMC) (Pauliuk, 2022). A detailed description of the procedure and the equations used is provided in SI1.

We present and discuss the results for RMI, GWP, LO, and WU footprints for two scenarios. The reference scenario depicts the countries’ recent (2015) demand and supply patterns, e.g., diets and transport modes, and technologies i.e., electricity mixes, and the efficient scenario, where electricity is provided from low-carbon sources, the meat intake is reduced by 50 %, and 25 % of the mobility covered by private transport is shifted to active mobility. Supplementary results for TMR, direct, and indirect stocks, as well as single scenarios for a transition into renewables, reduction of meat intake, and a shift from private transport to electric vehicles, public transport, and active mobility, are provided in SI2–4–5–6.

3. Results

3.1. Resources and emissions footprints to provide DLS

The resources and emissions to provide DLS around the world differ considerably depending on the socioeconomic and geographical context of the countries. With recent (2015) system technologies, the RMI is between 3 (Ethiopia) and 16 (South Africa) t/(cap*yr). Furthermore, impacts for GWP are between 1 (Ethiopia) and 7 (Mongolia) t CO₂ eq./ (cap*yr). For LO, the values are between 7970 (Iceland) and 1430 (Democratic Republic of the Congo) m²/cap, while for WU, they are

between 98 (Zambia) and 334 (Bangladesh) m³/(cap*yr) (Fig. 1A, C, E, G).

3.2. DLS footprints breakdown by DLS dimensions, products, and services

With recent (2015) technologies, the nutrition and mobility dimensions account for large shares of the material and emissions footprints (see bars in Fig. 2A–B). Together, they represent between 21 % (India) and 77 % (Iceland) of the total RMI, while for GWP, they account for 18 % (India) and 84 % (Iceland) of the total impacts. The flows associated with the nutrition dimension are the main drivers of LO and WU (see Fig. 2C–D). For LO, nutrition represents between 33 % (Democratic Republic of the Congo) and 86 % (South Sudan) of the total DLS, while contributions of nutrition to WU range from 51 % (Mongolia) to 85 % (Bangladesh).

Compared to current per capita resource consumption and emissions (FAO, 2021; UNEP IRP, 2024; World Resources Institute, 2022), countries can be divided into two groups. Shortfall – countries whose estimated DLS resource needs and emissions exceed current consumption and emissions levels – and surplus – countries where the current resources consumption and emissions exceed the DLS-related values estimated here (due to inequality, part of the population of these countries may be deprived of DLS). For materials, 29 countries (mostly in Africa) are in shortfall, while 129 countries currently have a surplus. For emissions, 58 countries are in shortfall, while 113 countries are in surplus. For land, 65 countries are in shortfall, and 107 countries have a surplus. Finally, 61 countries have water shortfalls, while in 109 countries, current water consumption exceeds DLS requirements (see black dots in Fig. 2).

With recent (2015) provisioning systems, electricity production accounts for up to 75 % (South Africa, which has the highest RMI of all countries, see Section 3.1) of the total RMI and up to 75 % (India) of the total GWP, mainly due to the high shares of fossil fuels (coal, gas, and oil) in the electricity mix of (87 % and 81 %, respectively). Private transport (passenger cars and 2-wheelers) accounts for up to 49 % (Canada) of the total RMI, while meat (fish, sheep, swine, chicken, and red meat) production accounts for up to 22 % (Central African Republic) of the total GWP (see Fig. 3A–C). Meat and milk production account for up to 79 % (South Sudan) and up to 24 % (Finland) of the total impacts of LO and WU, respectively. (see Fig. 3E–G).

3.3. DLS footprints in relation to current consumption and sustainability corridors

Our results indicate that with recent (2015) provisioning systems, providing a person with DLS in South Africa, Mongolia, Zimbabwe, Namibia, Botswana, and Mozambique will transgress the RMC threshold by 6–8 t/(cap*yr) for materials by 2050 (gray area in Fig. 2A), as suggested by the IRP (2014) as a sustainable corridor target (see SI4). Compared to the current material footprints of many industrialized countries e.g., ~30 t/(cap*yr) in the USA (UNEP IRP, 2024), the DLS-related material footprints appear small.

To get on track to limiting warming to below 2 °C, annual emissions in 2030 must be around 40 Gt CO₂ eq./yr or 4,7 ton CO₂ eq. cap/yr (divided by the 2030 population) (UN, 2024b). With recent (2015) provisioning systems, our results suggest that providing a person with DLS in 18 countries, e.g., South Africa, Mongolia or Canada, will exceed this emissions target, while in 158 countries, current emissions footprints of DLS are within the climate targets (bars and blue line in Fig. 2B).

Low DLS-related material uses and emissions result from a combination of several factors, including low-carbon electricity production (e.g., Paraguay 100 %), a low contribution of nutrition (low kcal/day and low animal protein share, e.g., North Korea), or low transport distances (e.g., 3549 pkm in Hong-Kong) (see SI4). These results show the importance of renewables and a diet low in animal protein to decouple

Current system technology

A. Raw Material Input: t/(cap*yr)



Efficient scenario

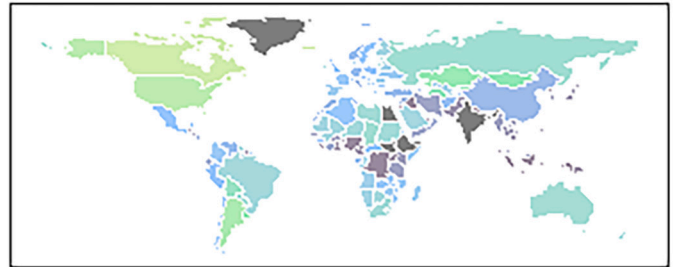
B. Raw Material Input: t/(cap*yr)



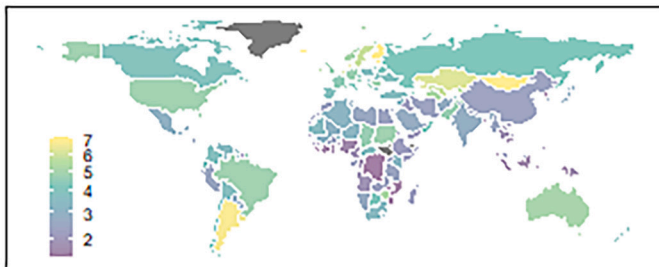
C. Global Warming Potential: t CO₂/(cap*yr)



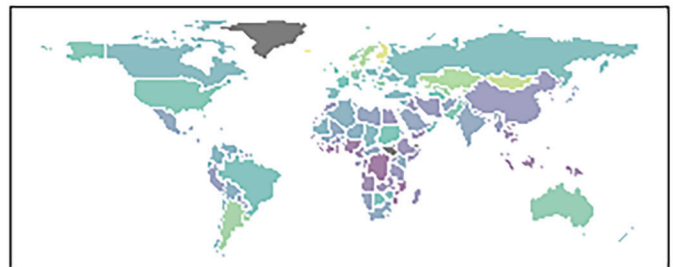
D. Global Warming Potential: t CO₂/(cap*yr)



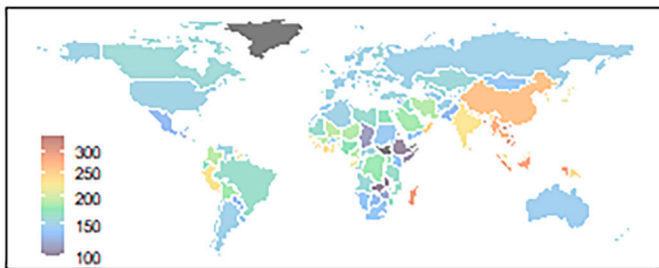
E. Land Occupation: Thousand m²/cap



F. Land Occupation: Thousand m²/cap



G. Water Use: m³/(cap*yr)



H. Water Use: m³/(cap*yr)

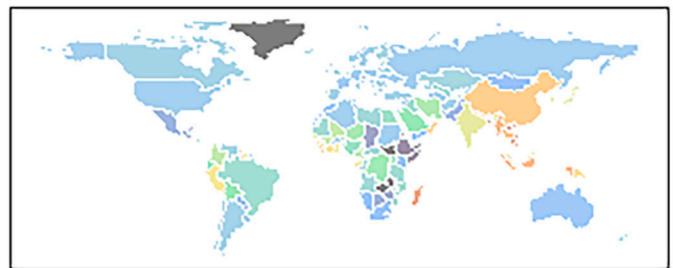


Fig. 1. Four environmental footprints to provide a person with a decent living standards (DLS) by country. Left side: Reference scenario with 2015 demand, energy mix, industrial structure, and trade patterns. Right side: Efficient scenario. (A–B) Raw material inputs (C–D). Global warming potential. (E–F) Land occupation. (G–H). Water use. Numerical values are listed in SI7.

DLS provision from climate impacts.

3.4. Scenario analysis

A transition to low-carbon energies can substantially reduce the material use and emissions of providing DLS. Substantial savings can be expected in South Africa (75 % of materials) and India (75 % of GHG emissions). In contrast, no major savings are expected in Central Africa or Ethiopia (less than 1 %), mainly because in these countries, almost 100 % of the electricity is provided by hydropower (see SI2). Alternatively, LO and WU savings are up to 29 % (Guatemala) and 11 %

(Mongolia).

Shifting to a diet low in animal protein (50 % less) could save up to 10 % of the RMI (Bahamas) and GWP (Central Africa). The savings in LO and WU are estimated to be up to 32 % (Zimbabwe) and up to 1 % (Poland), respectively. For WU, negative effects can be observed in 32 countries, e.g., up to –6 % (Mongolia), mainly because the savings achieved by the reduction of meat consumption are canceled out by the increase in consumption of products with a higher water footprint. For example, each kg of meat consumed has a water footprint between 0,06–0,4 m³, while rice has a footprint of 1,7 m³/kg (values directly from ecoinvent; license required).

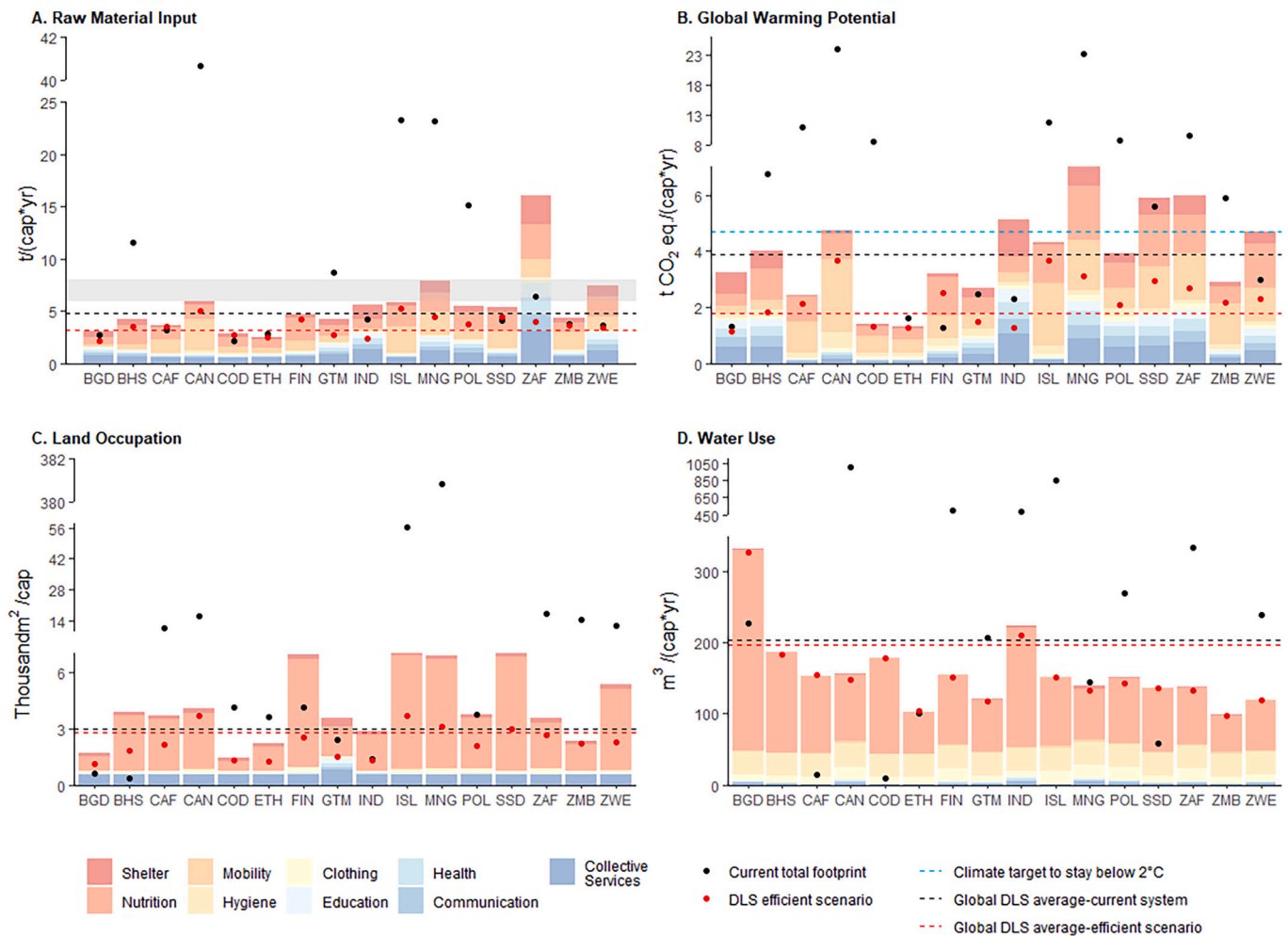


Fig. 2. Average annual resource flows and emissions to provide a person with decent living standards (DLS) for the countries mentioned in the main text. A) Raw material inputs. The gray area represents the sustainable corridor for material consumption from Bringezu (2015). B) Global warming potential. C) Land occupation. D) Water use. The bars represent the DLS footprint under the 2015 system technology. The black dots show the 2015 total material, emissions, land use, and water use per capita footprint of each country from the UNEP IRP (2024), the World Resources Institute (2022), HYDE (2023), and the FAO (2021), respectively. The red dots in each panel represent the impacts of providing DLS in the efficient scenario. The black and red dashed lines show the population-weighted global average DLS impacts for the reference and efficient scenarios, respectively. The blue dashed line shows the climate target to stay below the 2 °C (UNEP, 2024). Numerical values are listed in SI7. (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

Alternatively, assuming that all countries promote public transport, a 25 % shift from private transport (between the 2DS and B2DS scenario from the IEA (2017)) to trains and buses could bring savings in RMI and GWP of DLS provision of up to 8 % and 10 %, respectively (both for Canada). A 25 % shift from private combustion vehicles to electric vehicles would raise RMI and WU by up to 2 % and 1 %, while savings for GWP could be up to 4 % (all three for Canada). Finally, a 25 % shift of private transport to active mobility, i.e., bikes, would bring 12 % savings in RMI, 13 % in GWP, and 1 % in WU (all for Canada). Canada is a particular case because currently, around 95 % of transport needs are covered by private passenger vehicles.

A transition to low-carbon energies, a diet low in meat protein, and a shift into active mobility all together could bring DLS impact savings up to 76 % (South Africa), 75 % (India), 37 % (Guatemala), and 7 % (Serbia) for the impacts of RMI, GWP, LO, and WU, respectively (red dots in Fig. 2). Detailed information on the scenario analysis can be found in SI2, while the results for each scenario and country can be found in SI4.

3.5. Global savings potential for a transition into renewables and a change in diets and transport preferences

With recent (2015) system technologies, electricity provisioning is responsible for 12 Gt/yr or 34 % of the total materials (35 Gt/yr) and 15 Gt CO₂ eq./yr or 50 % of the total emissions (29 Gt CO₂ eq./yr) required to provide DLS for all. Electricity also accounts for 0,3 million km² or 1 % of the total land (22 million km²) and 53 billion m³/yr or 3 % of the total water (1518 billion m³/yr) required. A transition to a clean electricity grid can reduce global DLS-related material use and GHG emissions by 29 % and 49 %, respectively. Around 1 % and 3 % savings can be expected in land occupation and water use.

Furthermore, meat consumption is globally responsible for about 3 Gt/yr or 8 % of the total materials, 1,8 Gt CO₂ eq./yr or 6 % of the total GHG emissions, 4 million km² or 18 % of the total land, and 70 billion m³/yr or 5 % of the total water required for DLS. Shifting to a diet low in animal protein (50 % less) could save around 3 % of the global total RMI and GWP related to DLS provision, while savings of around 6 % and less than 1 % of the total LO and WU could be expected. This is mainly because animal protein intake (sheep, swine, chicken, and red meat) accounts only for 17 % and 6 % of the total global RMI and GWP

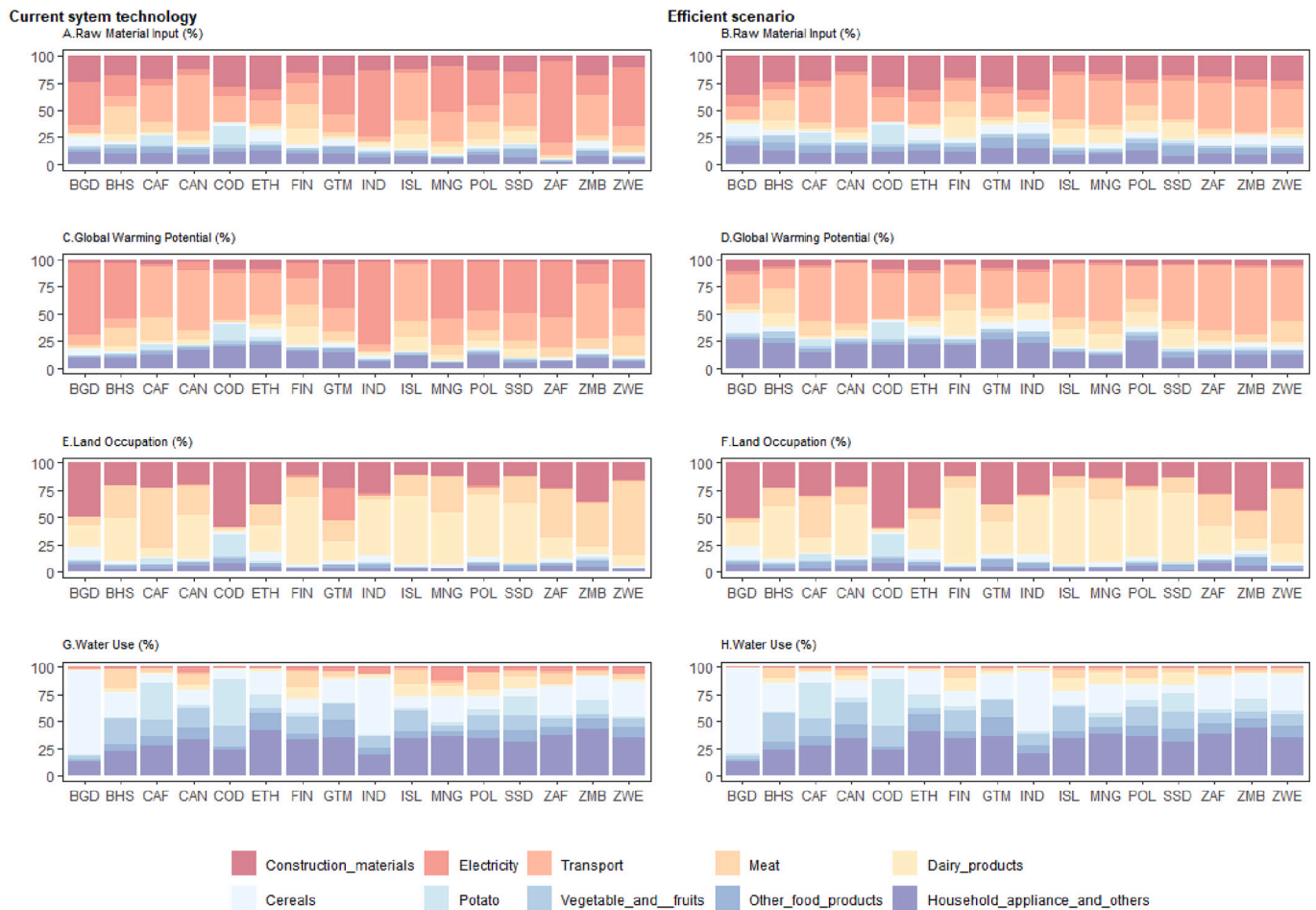


Fig. 3. Breakdown of average annual resource flows and emissions to provide a person with decent living standards (DLS) by ecoinvent processes for countries mentioned in the main text. Left panels: Reference scenario. Right panels: Efficient scenario. (A–B) Raw material inputs (C–D). Global warming potential. (E–F) Land occupation. (G–H). Water use. Numerical values are listed in SI7.

required to provide DLS, while for LO and WU, it accounts for 18 % and 5 %, respectively. Moreover, the savings achieved by the reduction of meat consumption are canceled out by the increase in consumption of products with a higher footprint (see Section 3.4).

Transport is responsible for approximately 6 Gt/yr or 17 % (RMI), 5,6 Gt CO₂ eq./yr or 19 % (GWP), 0,05 million km² or < 1 % (LO), and 8 billion m³/yr or 1 % (WU) of the global DLS footprints, respectively. A 25 % shift from private transport to public transport, electric vehicles, or active mobility could bring global savings of around 2 % for RMI, between 1 % and 3 % for GWP, and less than 1 % for LO and WU. The low savings for LO and WU are mainly because mobility is responsible for less than 1 % of the total impacts in these categories globally.

Providing a DLS for all with low-carbon energies, less meat consumption, and active mobility (efficient scenario) would require about 24 Gt/yr (materials), 14 Gt CO₂ eq./yr (emissions), 20 million km² (land), and 1464 billion m³/yr (water). In this scenario, providing DLS for all results in savings of 32 %, 16 %, 7 %, and 4 %, respectively, compared to the recent (2015) system.

Our results are consistent with previous DLS impact estimates and support the claims that a combination of supply- and demand-side solutions is needed to stay within planetary boundaries (Creutzig et al., 2018).

3.6. Global DLS gaps

With recent (2015) provisioning systems and without considering future decarbonization or population trends, around 13 Gt/yr or 14 % of

the current annual material extracted (RMC of 91 Gt/yr in 2015) (UNEP IRP, 2024), is required to remove all DLS deprivation globally ('close the DLS gap'). Approximately 33 % of this amount is related to public activities (collective services). Around 18 % and 14 % are required to provide adequate mobility and shelter, respectively. Furthermore, 3 % of these materials are required to eradicate malnutrition.

The estimated amount of emissions related to remove DLS deprivations is around 12 Gt CO₂ eq/yr or 22 % of the current emissions (54 Gt CO₂ eq/yr in 2015) (Forster et al., 2024). Around 31 % of this amount is needed for collective services, while 17 % and 13 % are required for mobility and shelter. Furthermore, 2 % of these emissions are to eradicate malnutrition.

Eradicating global DLS deprivation requires around 3 million km² or 2 % of the total agricultural land currently occupied (158 million km² in 2015) (HYDE, 2023). Approximately 53 % of land requirements are needed for collective services, while 19 % is needed to provide adequate nutrition.

Finally, the water required to eradicate DLS deprivation was estimated to be 88 billion m³/yr or 2 % of the current global water consumed (3866 billion m³/yr in 2015) (FAO, 2021). Around 52 % and 16 % of this need is to provide adequate nutrition and public services.

Closing the DLS gap in three countries, India, China, and Indonesia, requires around 50 %, 55 %, 42 % and 50 % of the materials, emissions, land, and water required to remove all DLS deprivation globally mostly due to the population size of these three countries (see bars in Fig. 4A–D) (SI1 provide a figure in per capita terms for comparison).

Removing the deprivation of access to collective services globally

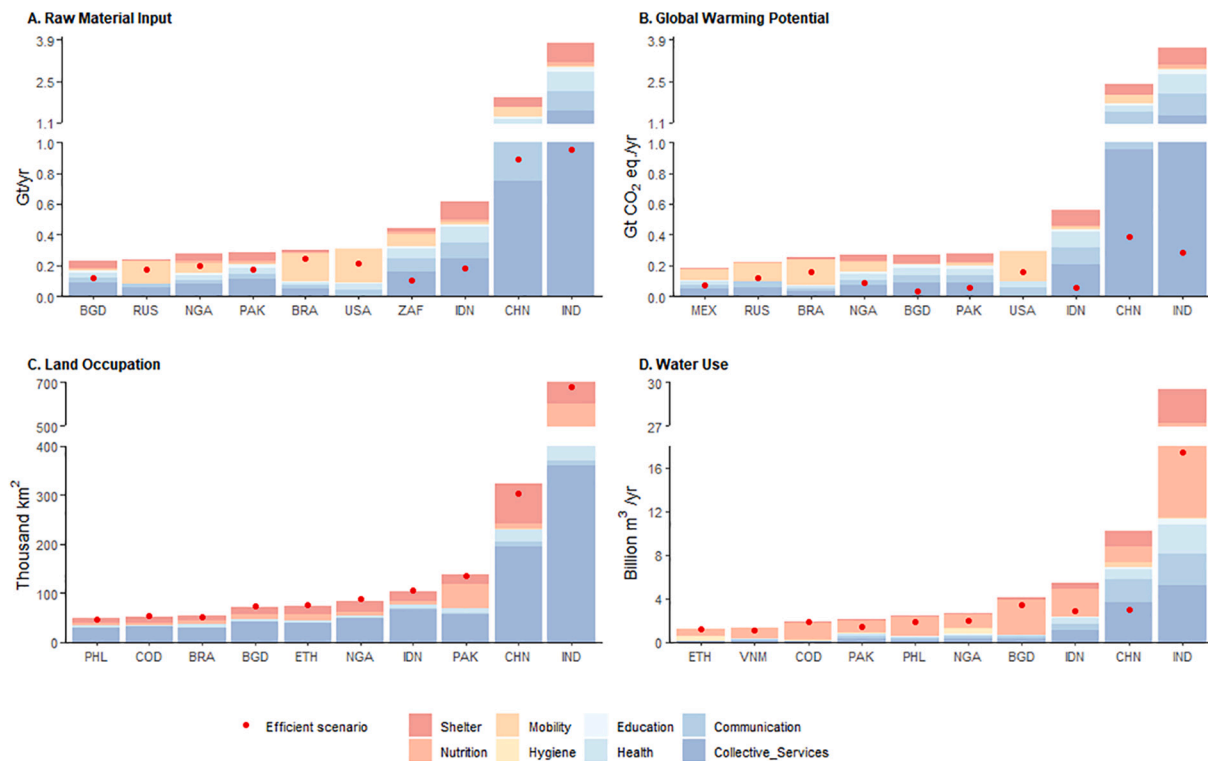


Fig. 4. Average annual resource flows and emissions to close DLS gaps in countries with major DLS deprivation. Top 10 countries shown for each footprint category. A) Raw material inputs. B) Global warming potential. C) Land occupation. D) Water use. The red dots in each panel represent the impacts of closing DLS deprivation in the efficient scenario. Numerical values are listed in SI7. (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

requires large amounts of resources and emissions, mainly due to four factors. First, we assumed high values for the collective services gap in developing countries (between 75 % and 25 % of the current 4,6 m²/cap threshold) depending on their country's gross national income per capita taken from the [World Bank \(2025\)](#)(see SI1–2 for details) mainly due to the lack of data to estimate current collective services deprivation at the country level. Second, the population of the countries for which we assumed high deprivation in public services accounts for about 84 % of the global population. Third, the quantities of materials and energy required to build and operate the buildings to provide public services are large compared to other buildings needed for shelter, education, and health (see SI1–2). Fourth, construction materials and energy provisioning are major drivers of environmental impacts (see [Fig. 3](#) and SI4).

Excluding collective services from the total DLS gaps translates into much less impact to close all DLS deprivation globally. Less than 9 % (materials), 17 % (emissions), 1 % (land), and 2 % (water) of the current levels. Under this assumption, around 27 % and 25 % of the total material needs and emissions, respectively, are required to close the gaps in mobility, while around 41 % and 63 % of the total land and water are required to close the nutrition gap.

Closing the global DLS gap in a scenario with a transition to low-carbon energies, a diet low in meat protein, and a shift to active mobility would reduce the need for resources and emissions as follows: By about 6 Gt/yr or 7 % of the current annual material extracted, 3 Gt CO₂ eq/yr or 1 % of the current GHG emissions, 3 million km² or 2 % of the total agricultural land currently occupied, and 57 billion m³/yr or 2 % of the current global water consumed.

At the country level, removing DLS deprivation (including collective services) requires up to 220 % (recent system technology) or 82 % (efficient scenario) (Mozambique) of the current RMC of the country. Up to 71 % (recent system technology) or 27 % (efficient scenario) (Somalia) of the current GHG emissions are required to close DLS deprivation in the country. For land, up to 181 % (recent system technology)

or 185 % (efficient scenario) (Mauritius) of the current agricultural land occupied is required. Finally, for water use, up to 267 % (both scenarios) (Democratic Republic of the Congo) of current water use is required (see [Fig. 5](#)).

4. Discussion

4.1. DLS footprints compared to current consumption levels and inequality

We found that efficiently providing DLS for a population of 7,3 billion in 2015 ([UN, 2024b](#)) with renewable energies, a diet with lower meat consumption, and active mobility in a stationary setting would require a material footprint of around 24 Gt/yr, from which about 6 Gt/yr are currently not provided (DLS gap). These values represent around 26 % and 7 % of the current annual material extracted (RMC 91 Gt/yr in 2015) ([UNEP IRP, 2024](#)).

The GHG emissions required to provide the global population with DLS are estimated at 14 Gt CO₂ eq/yr, from which about 3 Gt CO₂ eq/yr are currently not provided. These emissions represent around 26 % and 1 % of current emissions (54 Gt CO₂ eq. in 2015) ([Forster et al., 2024](#)).

The land occupation required to provide a DLS for all was estimated at 20 million km², from which around 3 million km² are currently lacking. These land needs represent around 13 % and 2 % of the agricultural land (arable and pasture) currently occupied (158 million km² in 2015) or around 19 % and 3 % of the current pasture land used, respectively (106 million km² in 2015) ([HYDE, 2023](#)).

Globally, around 1464 billion m³/yr of water is required to provide the population with DLS, from which about 57 billion m³/yr is currently not provided. These needs represent around 38 % and 2 % of the total water consumed (3856 billion m³/yr in 2015) ([FAO, 2021](#)).

Compared to a scenario of recent (2015) system technologies, a transition to renewable energy and changes in diet and transport

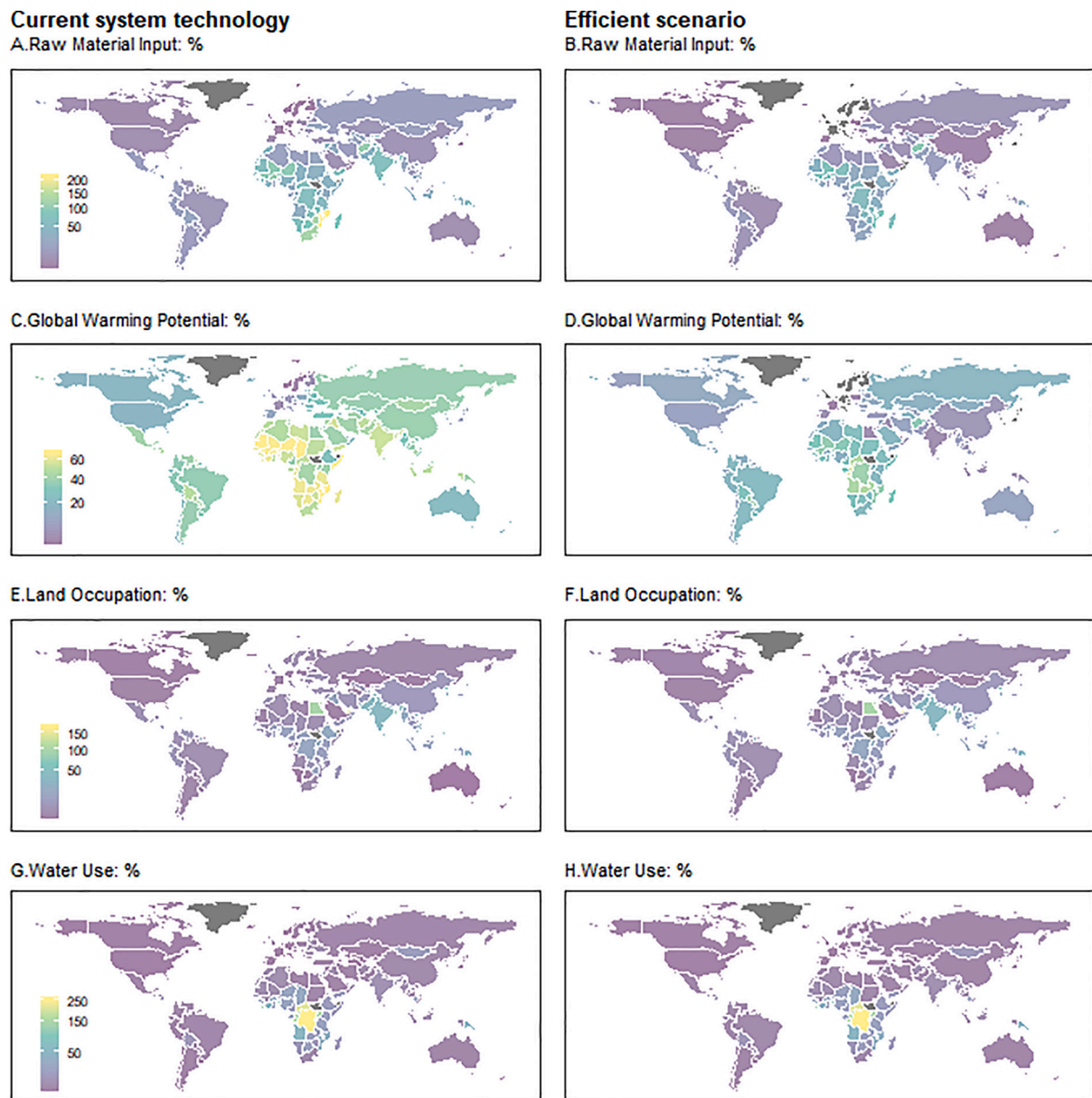


Fig. 5. Resources and emissions required to remove DLS deprivation, expressed as share of the countries' current consumption. Left panels: current system technology. Right panels: efficient scenario. (A–B) raw material inputs (C–D). global warming potential. (E–F) land occupation. (G–H). water use. Numerical values are listed in SI7.

preferences (see Section 3.5 and Fig. 4) would reduce the materials, emissions, land, and water associated with closing global DLS deprivation by 53 %, 77 %, 2 %, and 35 %, respectively.

Reductions in GHG emissions can be even more substantial than in our efficient scenario, if more ambitious climate policies are implemented, such as (1) the decarbonization of the production of materials such as cement, steel and chemicals (materials are responsible for 23 % of global GHG in 2015 (Hertwich, 2021)), (2) the complete phase-out of internal combustion engines, or (3) carbon dioxide removal (CDR) technologies. Many of these alternatives are already being implemented as part of the 2050 net zero targets of different countries.

Recent studies have found that persistent inequality substantially increases the energy requirements to secure DLS for all (Millward-Hopkins, 2022). In this sense, Pauliuk (2024) derived an analytical formula for estimating total consumption levels to ensure that the bottom decile of the population reaches DLS under inequality. For example, for a given level of inequality measured by the energy Gini coefficient (e.

g., 0,75 in South Africa, one of the most unequal societies in the world) (Olawumi Israel-Akinbo et al., 2018; Oswald et al., 2020), providing DLS to the bottom decile of the South African population under constant energy inequality would lead to seven times the current DLS footprint across the population ($6 \text{ t CO}_2 \text{ eq./cap*yr} * 7 = 42 \text{ t CO}_2 \text{ eq./cap*yr}$) (recent (2015) system technologies) or $21 \text{ t CO}_2 \text{ eq./cap*yr}$ (efficient scenario).

Thus, to provide DLS for all within the climate and environment targets by the middle of this century, supply and demand side strategies need to be complemented by efforts to reduce within-country inequalities (Millward-Hopkins and Oswald, 2023).

4.2. Limitations

We propose a basket of products and services to satisfy the DLS needs of each country. Thus, for example, for communication, we assume that a laptop, a phone, and internet access are sufficient, while other authors

have considered instead a TV and phone (Kikstra et al., 2021). In other words, we acknowledge that the DLS needs can be satisfied with some flexibility regarding products and services, each with different resources and environmental implications, depending on the regional and cultural context. This issue can be partially covered by a scenario analysis (see Sections 3.4) and Veléz-Henao and Pauliuk (2023).

Second, the ecoinvent database has limited coverage for some products, services, and regions. Thus, when modeling the provisioning of education, health, and collective services, we only account for the buildings that are representative of each service, i.e., we ignore additional equipment and appliances needed to deliver the service, e.g., medical instruments for healthcare, chairs, computers, and boards for education. Furthermore, the infrastructure required to support communications, i.e., the networks, servers, and cloud computing infrastructure, was not included. Regarding geographic coverage, we used country-specific electricity mixes provided by ecoinvent, while for the rest of the products, we used world-average technology (i.e., processes with global or rest-of-the-world geographical scope), e.g., for construction materials, food products, and transport modes (see SI2 for the background link exercise). We acknowledge that this approach leads to under/overestimations for some countries, but argue that the overall conclusions remain robust under this simplification. This is mainly because the production technologies for many goods, e.g., clothes or impacts of specific transport modes, do not differ much across regions and are traded globally.

These limitations can be tackled by a time-explicit modeling approach, such as a coupling of material flow analysis (MFA) with LCA (Barkhausen et al., 2023), prospective LCA (Sacchi et al., 2022), or a coupling of DLS provisioning systems to IAMs (Kikstra et al., 2024). For further discussion on the limitations of modeling DLS with LCA methods, see Veléz-Henao and Pauliuk (2023).

5. Conclusions and outlook

We added detail to the decent living standards framework by quantifying salient environmental pressure metrics of DLS and DLS gap, considering local contexts in 176 countries. We show that strategies, such as a rapid energy transition and other supply and demand side measures can help eradicate poverty while keeping environmental pressures within the planetary boundaries (Rockström et al., 2009; Steffen et al., 2015) and the Paris Agreements (UNFCCC, 2015).

Several means can increase the policy relevance of the DLS thresholds. First, context, culture, region, and city-specific DLS thresholds can guide local sustainability governance processes. Second, ethnical, gender, and age-related inequality within countries need to be included to derive context-specific DLS thresholds. Third, DLS represent the floor of sustainable consumption corridors and are thus part of the debate around poverty thresholds, inequality, and growth (Pauliuk, 2024). Finally, a roadmap of action is needed to make the DLS more applicable and useful to practitioners and policymakers.

CRedit authorship contribution statement

Johan Andrés Vélez-Henao: Writing – review & editing, Writing – original draft, Visualization, Validation, Software, Project administration, Methodology, Investigation, Funding acquisition, Formal analysis, Data curation, Conceptualization. **Jan Streeck:** Writing – review & editing, Data curation. **Jarmo Kikstra:** Writing – review & editing, Data curation. **Stefan Pauliuk:** Writing – review & editing, Visualization, Methodology, Conceptualization.

Declaration of competing interest

The authors declare the following financial interests/personal relationships which may be considered as potential competing interests:

Johan Andrés Vélez-Henao reports financial support was provided by

Horizon Program of the European Union. If there are other authors, they declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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Appendix A. Supplementary data

Supplementary data to this article can be found online at <https://doi.org/10.1016/j.ecolecon.2025.108819>.

Data availability

All data and results are available as SI

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