Global and national inventory assessment of temporary housing for on-site isolation of essential workers during extreme pandemics

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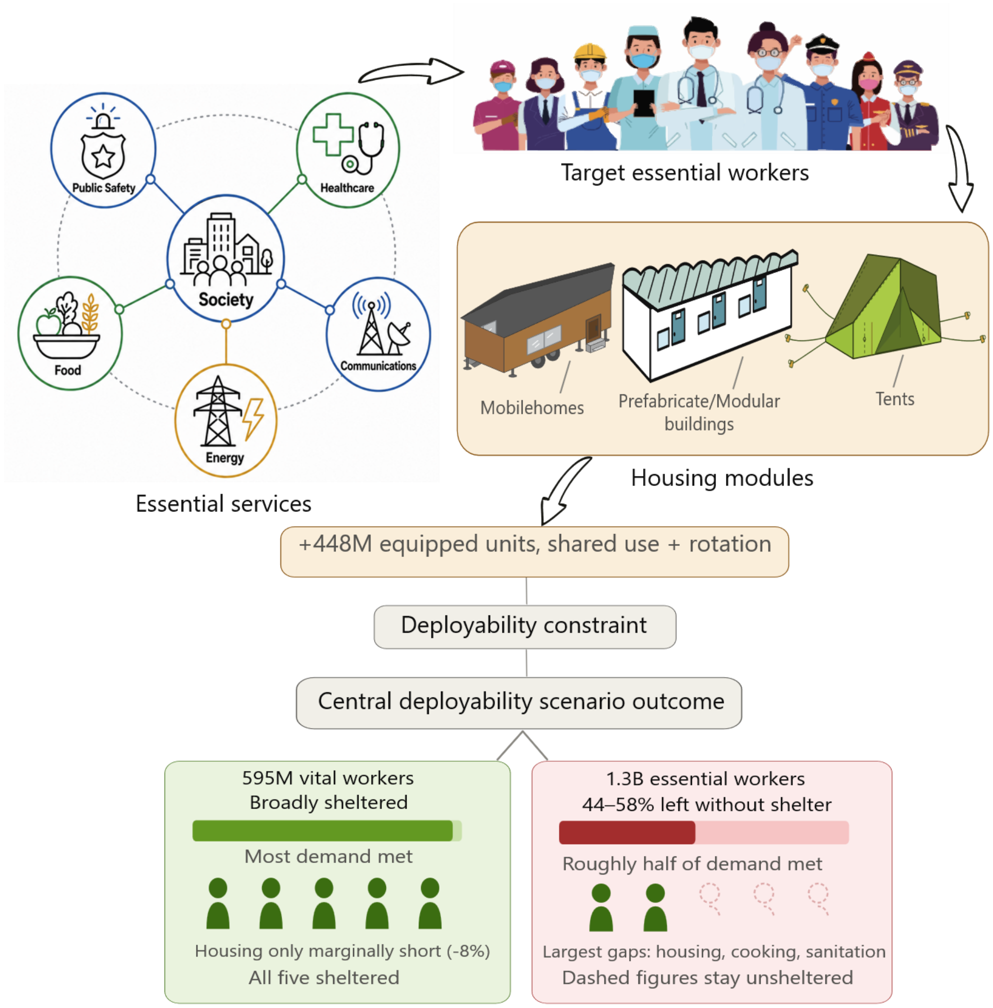
Abstract

Extreme pandemics pose severe risks to the continuity of critical services, yet quantitative infrastructure assessments for essential-worker isolation remain largely absent. This paper presents the first global and national assessment of whether existing physical stocks could shelter isolated workers, estimating the availability of 17 temporary-housing categories and six basic-amenity types across 199 countries against the demand of 1.3 billion essential workers (EW) and 595 million vital workers (VW). Results are reported globally, assuming an open worldwide pool, and nationally, assuming no cross-border trade. A central deployability scenario was adopted as the planning basis. Under this scenario, with full international trade, the world could accommodate 45% of the VW population in high-quality temporary housing and provide all VW with basic amenities; a further 47% would rely on low-quality temporary housing such as converted vans and tents, while the remaining 8% could not be covered. Although full EW coverage is not attained in any housing or amenity category, with deficits of roughly 44% to 58%, a controlled sharing protocol with scheduled rotation and disinfection converts most amenity deficits to surpluses. In contrast, without international trade, only 41 of 199 countries (21%) could accommodate all VW with high-quality temporary housing alone, a further 61 (31%) could do so once low-quality housing is included, and 97 (49%) could not cover their VW under any combination of available stock. These findings show that current global stocks provide a reasonable foundation for protecting vital workers but leave substantial gaps in the

absence of global trade, offering the first evidence base to guide national pandemic preparedness.



Graphical abstract.

Keywords: extreme pandemic, essential workers, temporary housing, on-site isolation, global catastrophic risk.

1. Introduction

The COVID-19 pandemic showed that humans are vulnerable to airborne infectious diseases that expose the fragility of our infrastructure, trade networks, and economic stability [1]. Worker shortages disrupted essential industries and limited their ability to provide basic needs to the public [2, 3]. It is becoming more apparent that future pandemics could involve pathogens that have high transmission potential and high mortality rates [4]. These pathogens could be zoonotic spillovers from nature or engineered viruses enhanced by advances in biotechnology and artificial intelligence. In the event of such outbreaks, the threat to society could increase significantly compared with what the world has recently experienced [5]. Therefore, preparations for future pandemics should include building resilience to these extreme events. Without this, the failure of any number of essential services could result in cascading failures of food production, water supply, energy distribution, and public safety systems [5, 6].

The history of pandemics shows that many agricultural systems are vulnerable to a pandemic that reduces labour availability [7]. During the Ebola outbreak in West Africa (2014–2016), for example, reduced labour availability contributed to declines in agricultural production, especially in rice production in Liberia, due to absenteeism from work caused by fear of contracting the virus and the quarantine of infectious individuals [8, 9]. The magnitude of impact that high-mortality pathogens can have on agricultural systems is further illustrated by another historical example, the 1890s rinderpest epizootic in sub-Saharan Africa. During this period, outbreaks wiped out over 90% of cattle populations across the region, creating extensive economic losses, social disruption, and famine [10, 11]. A similarly virulent pathogen capable of producing high infection rates in people could rapidly deplete the available workforce and trigger cascading forms of societal collapse [3, 12].

Keeping the key industries functioning during an extreme pandemic hinges on the continued availability of workers who cannot perform their roles remotely and must be physically present at their workplace [13]. Essential workers refer to the broader group of individuals deemed essential by governments during the COVID-19 pandemic. They are engaged in a wide range of in-person essential services such as agriculture and food production, energy supply, water and waste management, transportation and logistics, communication, manufacturing, public administration, and healthcare [13]. The absolute minimum subset of these workers required to maintain the basic functioning of society is referred to as vital workers. In an extreme catastrophe in which not all EW can be safely protected at work, keeping vital services running could provide time to scale up protections and restore all essential services back [14].

While high-efficiency personal protective equipment (PPE) could protect workers, the available supply is insufficient, and it is not feasible to wear PPE while sleeping [15].

Precedents from the COVID-19 pandemic demonstrate that on-site accommodation of essential workers is an actionable strategy rather than a purely theoretical one. To maintain electricity supply, several power utilities sequestered mission-critical control-room and generation staff at their facilities, housing them in recreational vehicles, trailers, and converted office spaces with meals delivered on site [16, 17]. A comparable measure was adopted in the water sector, where operators were accommodated within a municipal water-treatment facility to safeguard the continuity of drinking-water supply [18]. These examples illustrate the feasibility of on-site isolation when suitable accommodation and amenities are available. Conversely, the large-scale closed-loop arrangement implemented at an electronics manufacturing complex in Zhengzhou, China, where workers lived and worked on site under prolonged isolation, illustrates how inadequate provision of accommodation, food, and welfare can contribute to unrest and undermine the protective intent of such schemes [19]. Together, these cases underscore that the success of on-site isolation depends critically on the availability of adequate temporary housing and basic amenities.

Since societal stability depends on the continued protection of these workers, a complementary layer of protection is required to interrupt the transmission chains between workplaces and homes. To achieve this separation, this paper evaluates various types of temporary housing along with basic amenities that are intended to be low-technology, and low-cost, and rapidly deployable on site.. Ideally, single-occupancy units would maximize separation; however, when insufficient, shared accommodation (two to four workers per unit) could be employed alongside strict internal safety protocols.

2. Literature review

Although a significant number of studies [20–23] have considered deployable and scalable designs for temporary housing, they were often intended for a limited number of people, lacked basic amenities, and overlooked a range of temporary housing configurations. In this regard, Süalp et al. [24] investigated deployable prefabricated containers manufactured by BOXABL for post-disaster rehabilitation purposes. These foldable, origami-based container and panelised units were compared through expansion ratios, area-per-user metrics, and population-density calculations. They reported that the assembly of these foldable units can be assembled within hours using steel frames, sandwich panels, and fibre-reinforced concrete floors. While their work covers rapid on-site transport and basic amenities, it lacks a study on pathogen-specific ventilation and basic amenities. Similarly, Adeyemi et al. [25] investigated modular prefabricated units for affordable housing shortages. Off-site standardised steel, engineered-wood, and concrete components were produced for on-site bolted assembly. These materials were shown to have good scalability and minimal weather dependence. Although their approach offered cost-effective rapid deployment, isolation from biological threats was overlooked in their study. Smolova et al. [26] assessed prefabricated modular healthcare facilities for pandemic isolation units. Load-bearing wall and corner-post modules were zoned into clean, semi-contaminated, and contaminated areas with dedicated movement channels, allowing rapid scaling to 1,600-patient capacity. For ventilation, they employed an individual negative-pressure system and reported that it could achieve acceptable air circulation efficiency. Montalbano et al. [27] investigated sustainable temporary housing units for natural or human-caused disasters. A requirements-based design strategy integrated case studies with environmental, economic, and social criteria, yielding modular prefabricated systems assembled on-site from glued laminated timber frames, hempcrete blocks, and oriented strand boards. The resulting compact modules (33 m^2 for single occupancy) provided thermal regulation; however, their research lacked dedicated airborne filtration.

Some researchers [28–30] have used prefabricated units for medical purposes, particularly as hospitals to accommodate clinical staff and patients. This approach provided a new way to create isolation capacity to respond quickly to COVID-19 outbreaks around the world. In this context, Neha et al. [31] examined Wuhan emergency hospitals which were constructed using prefabricated steel structural systems and composite modules assembled on site to create separate treatment, logistics, and staff areas within the same temporary hospital to relieve pressure on existing health care systems. Anderson et al. [32] developed a temporary housing design for clinical staff during the COVID-19 pandemic. Their research focused on balancing infection control with quality of life and overall resilience. They reported that installing supplemental exhaust ventilation in addition to upgrading filters, was an effective strategy to ensure clean air in isolation areas. Similarly, Abbasi et al. [30]

applied modular prefabricated materials to construct a hospital where a building information modeling (BIM) approach was considered to improve the project's quality. Extending this practice through the use of BIM, Li et al. [33] and Chen et al. [34] described how container housing could be created using cold-formed thin-walled steel framing and composite panels, allowing for the parallel manufacturing of the modules off-site and subsequent on-site assembly of the "three zone, two-channel" with negative-pressure wards, using computational fluid dynamics (CFD) airflow modeling to optimize their design. These designs enabled the separation of staff sleeping areas and the provision of surge capacity for thousands of patients; however, neither of these studies discussed the number of basic amenities necessary for long-term onsite housing of essential workers.

Building on hospital-scale examples, further research investigated affordable modular buildings, mobile cabins, dormitory adaptations, and ventilation strategies to support worker isolation and resilience during pandemics. Gatheeshgar et al. [35] and Gbadamosi et al. [36] evaluated steel-framed modular units and temporary mobile cabins that were constructed off-site from prefabricated cold-formed steel joists and breathing-panel sidewalls. They also applied negative-pressure rooms and full fresh-air ventilation to circulate the air inside the shelters. Dişli et al. [37] and Choi et al. [38] studied adaptations to existing dormitory layouts and disaster-shelter planning guides, with the aid of space-syntax analysis and stakeholder input, to introduce flexible partitions and natural window ventilation. They also identified minimum bed-spacing requirements for the dormitory layouts. Several studies have examined ventilation strategies for limiting airborne transmission, though they report performance targets using different, non-interchangeable metrics Thatiparti et al. [39] analysed a ceiling-ventilated airborne-infection-isolation room operating at approximately 12 air changes per hour (ACH), consistent with the established hospital isolation standard, but found that this configuration did not reliably protect a nearby occupant from cough aerosols. Navaratnam et al. [40] and Aliabadi et al. [41] reviewed ventilation-system types (mixing, displacement, natural and hybrid) together with High Efficiency Particulate Air (HEPA)/ Minimum Efficiency Reporting Value (MERV) filtration and Ultraviolet Germicidal Irradiation (UVGI) disinfection as qualitative design measures rather than prescribing a single airflow target. Azuma et al. [42], using the Wells–Riley framework, expressed adequacy in per-occupant terms, illustrating that documented transmission events occurred where ventilation rates fell to well below 1 L/s per person. Higher air-change rates are also required at high occupant densities, where crowding occurs, whereas comparatively lower rates are sufficient when occupants are well separated [43]. Other researchers [43–46] have reported that natural ventilation can help control infection in healthcare settings by using wind and buoyancy to move fresh outdoor air through buildings, thereby diluting airborne pathogens effectively.

Regarding temporary housing for healthcare workers, Emmanuel et al. [47] recommended flexible modular layouts as temporary housing along with the integration of natural and mechanical ventilation and open-ended corridors to maximise airflow through the housing. They reported that their measures support infection prevention without the need for high-tech construction for on-site isolation. Dbouk et al. [48] investigated the potential of domestic air purifiers in reducing airborne virus transmission. They used Computational Fluid Dynamics (CFD) simulations to examine the optimal placement of air purifiers within a room and supplementary ceiling fans, and found that the room's corners were the most effective locations for ventilation devices to remove virus particles, compared with central positioning. Walker et al. [49] provided practical guidance for creating protected spaces within homes to minimise SARS-CoV-2 transmission. Adapting hospital-grade "isolate, dilute, filter" principles, the work proposed portable HEPA cleaners, directional airflow, negative-pressure zones for infected individuals, and positive-pressure protected areas for vulnerable occupants. These approaches indicate measures for continuous filtration and provision of basic amenities measures that are closely aligned with the requirements for safe, shared or single-occupancy on-site housing. Park et al. [50] developed a compact mobile sterile-chamber isolation unit for rapid deployment during airborne infectious disease outbreaks. The van-mounted chamber incorporated negative-pressure ventilation at –2.5 Pa, together with upper-room UV light and hypochlorous acid (HOCl) spray disinfection, achieving over 99% virus elimination within 3–4 minutes. This scalable solution illustrates how mobile units could provide rapid worker protection, offering a deployable model that complements larger modular shelters in extreme-pandemic scenarios. Other researchers have reported similar findings [51, 52].

Although the literature provides valuable insights into modular construction, rapid deployment, and ventilation strategies for emergency healthcare or post-disaster shelters, to the best of the authors' knowledge, no study has examined the global and country-level quantitative availability of temporary housing modules tailored to an extreme pandemic scenario requiring full on-site isolation of all essential workers. Existing research has predominantly considered a limited range of temporary housing typologies designed for a narrower group of personnel, namely healthcare workers, whereas the term “essential workers” encompasses a considerably broader population whose absence could critically undermine both key industries and societal stability. This study addresses that gap, and its principal contributions are as follows:

- Quantitative inventory of on-site isolation infrastructure for the full essential workforce. To the best of the authors’ knowledge, this is the first study to estimate the availability of temporary housing and basic amenities for the on-site isolation of all essential workers and the smaller subset of vital workers, rather than for healthcare workers alone, during an extreme pandemic.
- A comprehensive, multi-category stock catalog at global and national scales. The analysis systematically catalogs 17 categories of temporary housing alongside six basic-amenity types, covering heating, cooling, sanitation, cooking, and refrigeration, and estimates their coverage for both the VW and EW groups across 199 countries.
- A deployability framework bridging theoretical stock and practically usable capacity. Three deployability scenarios—low, central, and high—are introduced to translate full-availability stock estimates into realistically deployable capacity, explicitly accounting for private ownership, existing occupancy, and logistical barriers.
- A controlled sharing protocol for constrained amenities. A scheduled rotation and disinfection protocol is developed to evaluate how shared use of scarce amenities could extend effective coverage when stocks are insufficient.

Together, this inventory-and-deployability framework maps the infrastructure bottlenecks at both global and national levels, providing a quantitative evidence base for emergency preparedness planning.

3. Research Methodology

This study employed a market-size-based global inventory estimation methodology combined with gross domestic product (GDP)-proportional allocation to quantify the worldwide and country-level availability of temporary housing modules and basic amenities suitable for the on-site isolation of workers. The approach relied on publicly available 2024 market data, compound annual growth rates (CAGRs), product lifespans, national GDP figures, and employment statistics to derive both aggregate stocks and per-country distributions. All calculations were performed under the assumption that CAGRs remained constant over times. Global aggregate results treat the world as a single pool of stock and demand and therefore assume that trade remains open so that a surplus in one country can offset a deficit in another. Country-level results assume no cross-border trade during a pandemic, so that each country must meet its own demand from its own stock.

3.1. Global Stock Estimation

Annual global market size data (in USD) for each temporary housing module and basic-amenity category in the base year 2024 were first converted to physical units, with the data source for each subtype listed in Appendix Table A. The number of units traded in 2024 was estimatedby dividing the market value by the average global unit price:

Equation 1

$$N_{2024} = \frac{M_{2024}}{P}$$

where N_{2024} is the number of units sold in 2024, M_{2024} is the annual global market size in USD, and P is the average unit price in USD. Cumulative global stock was then back-calculated over the product's lifespan L (in years) by applying the compound annual growth rate r to reconstruct historical trade volumes from the start of the lifespan to 2024. The total available stock S is given by the geometric series summation:

Equation 2

$$S = N_{2024} \sum_{k=0}^{L-1} (1 + r)^{-k}$$

This formula yields the worldwide inventory of each module type and equipment item as of the end of 2024, assuming constant CAGR and full availability of all previously traded units.

3.2. Country-by-Country Allocation

In the absence of harmonised, country-level inventories for most of the housing and amenity categories considered, the global stock of each product was disaggregated at the national level using an economic-activity proxy. Rather than allocating stocks in proportion to aggregate national output alone, the allocation was weighted by the share of the economic sector most closely associated with the product, so that the distribution reflects not only the size of the country's economy but also the relative importance of the relevant productive sector within it. This sector-weighted approach was adopted because the production, ownership, and installed base of a given product tend to scale with the corresponding sector of economic activity more closely than with total output; for example, the stock of heating and cooling equipment is more accurately represented by the size of a country's energy sector than according to its overall gross domestic product (GDP). Within Equation 4 and Equation 5 below, this sector weight is assigned for each product and country: housing categories were weighted by each country's housing- and construction-related share of industrial value added, heating, cooling, and refrigeration equipment by the energy-sector share, and the remaining amenity categories by their most representative sectoral indicator. National GDP figures for 2024 were obtained from World Bank development indicators compiled by Our World in Data [53], the housing-sector weighting was derived from the World Bank industry value-added indicator [54], and the energy-sector weighting from compiled global energy statistics [55]; comparable sector statistics from reliable international sources were used for the other product categories. The allocation procedure is formalised in Equations 3 to 5.

To distribute global stocks to individual countries (199 countries analysed), each country's share of global GDP in 2024 was first computed as:

Equation 3

$$C_i = \frac{GDP_{i,2024}}{GDP_{world,2024}}$$

where C_i is the GDP contribution share of country i. For each product category, the country-specific market share percentage $MS_{i,j}$ (relative to the global market for product j) was multiplied by C_i to obtain the product-sector GDP contribution. These values were summed across all countries and then normalised to produce the final share of each country within the global product sector:

Equation 4

$$Share_{i,j} = \frac{C_i \times MS_{i,j}}{\sum_{i=1}^{199} \quad (C_i \times MS_{i,j})}$$

The country-level stock for each product was finally obtained by multiplying the global stock S_j by the normalised share:

Equation 5

$$Stock_{i,j} = S_j \times Share_{i,j}$$

In the equations above, amenity demand was assessed on a per-worker basis without adjustment for local climate, so heating and cooling requirements were applied uniformly across all countries and territories; the resulting national figures for thermal amenities should therefore be read as upper bounds on requirement rather than climate-specific estimates. The same normalized-share procedure was applied across all products, with only the underlying sectoral weighting changing between categories. This ensures that the national allocations remain internally consistent and sum to the global stock of each product, while reflecting category-specific economic structure. The complete set of sectoral weightings and the global stock totals used as inputs to this procedure are provided in the Appendix to support full reproducibility of the national estimates [56-60].

The same GDP-proportional procedure was applied to estimate the numbers of plumbers and electricians available in each country. These two trades represent the main labour requirements for the plumbing and electrical work involved in equipping the temporary housing modules. Among the housing categories considered, only prefabricated foldable units require any structural assembly on site, a task that does not demand specialised construction trades; the principal skilled-labour constraint therefore arises from connecting water and sanitation systems and from installing and wiring electrical equipment, tasks that must be carried out by qualified plumbers and electricians, respectively. Thus, it is important to ensure that the necessary installation tasks can be completed within the targeted one-month deployment timeframe [61-68].

Asubset of housing categories, including vehicles and vacant homes, was estimated using more direct national statistics to estimate the global-and national-level stocks. For these categories, country-level stocks were estimated first and then summed to obtain the global stock, as summarized below.

- ✓ **Vehicles:**

The number of vehicles in each country was obtained directly from national vehicle statistics [61]. Because only a portion of the vehicle fleet is suitable for conversion into single-occupant accommodation (vans and school buses), the number of these vehicles was approximated by the share of vans within the total vehicle fleet, estimated from the ratio of the global van market [69] to the total global vehicle market [70]:

Equation 6

$$R_{vehicle} = \frac{M_{target\ vehicle}}{M_{vehicle}}$$

where $R_{vehicle}$ is the ratio of the number of target vehicles to total vehicles, $M_{target\ vehicle}$ is the global market size of the target vehicle category, and $M_{vehicle}$ is the global market size of vehicles of all types. Applying the reported values for corresponding market sizesyields $R_{vehicle}$ = 190.45B / 1,292.42B ≈ 0.147. The number of convertible vehicles in country i was then obtained as:

Equation 7

$$V_i = C_i \times R_{vehicle}$$

where V_i is the number of convertible vehicles and C_i is the total number of cars in country i. The global vehicle stock was obtained by summing across all countries as below:

Equation 8

$$V_{total} = \sum V_i$$

✓ **Vacant buildings:**

The stock of these spaces in each country was estimated by applying the national housing vacancy rate to the total number of households [71]:

Equation 9

$$H_i = v_i \times N_i$$

where H_i is the number of vacant homes, v_i is the housing vacancy rate, and N_i is the number of households in country i. The number of households in each country was obtained from compiled national statistics [62]. The global vacant-home stock was obtained as:

Equation 10

$$H_{total} = \sum H_i$$

The complete set of input parameters used to derive the global stock of each housing and amenity sub-type, including the annual market size, market revenue share, average unit price, average lifespan, and compound annual growth rate, together with the resulting estimated stocks, is provided in Appendix (see Table A).

3.3. Estimation of worker populations requiring housing

The number of workers requiring housing was based on the estimates of global and country-level estimates of EW and VW counts modeled by Ng et al. [14]. They calculated EW populations from an ILO report on non-telecommutable essential work and VW populations by applying a more stringent vital subset of four-digit ISCO-08 occupations to the ILO data. An additional indoor filter was applied to obtain the subsets of EW and VW working indoors.

For this study, the total counts for EW and VW were used, because workers who work outdoors still require protection while inside their accommodation. Additionally, the two-digit ISCO-08 codes 61 ("Market-oriented Skilled Agricultural Workers") and 63 ("Subsistence Farmers, Fishers, Hunters and Gatherers") were removed. These are likely to account for the majority of farm owners and smallholder farmers who already live on the property where they work. The ISCO-08 code 92 ("Agricultural, Forestry and Fishery Labourers") was not removed, as these workers are likely to be people who do not own the farm and work there as employees or laborers. These people would need to be provided with safe emergency housing.

3.4. Uncertainty bounds and deployable-stock scenarios

The inventory estimates developed in the preceding sections describe the theoretical stock potentially available for emergency repurposing rather than the fraction that would necessarily be deployable during an extreme pandemic. The deployable share of each category is constrained by private ownership, preexisting occupancy, legal and administrative barriers, the physical condition of installed assets, ongoing commercial use, household dependence on fixed assets, and possible disruption of international trade. Conversely, emergency procurement, voluntary mobilisation, corporate cooperation, government requisitioning, military logistics, and prioritisation of vital sectors could increase the fraction of stock that becomes available during a severe crisis. The baseline inventory estimates should therefore be interpreted as theoretical upper limits rather than guaranteed deployable capacity.

To represent this uncertainty transparently and reproducibly, a deployability framework was developed. Three deployability scenarios, namely low, central, and high, were defined for each category of stock. The framework distinguishes between two structurally different categories because the deployability constraints that apply to a vacant dwelling are not analogous to those that apply to a fixed amenity installed within an occupied dwelling. Two complementary anchor types were therefore adopted, each based on empirical quantities, and applied uniformly across all 199 countries since national-level vacancy and inventory data are not consistently available for every category.

3.4.1. Anchor type A: Vacancy-based formulation for housing

For all temporary housing categories, the deployability factor was anchored to the vacancy rate of the corresponding stock, defined as the fraction of the inventory that is currently unused at any given time and could therefore be mobilized without displacing existing users. Vacancy rates were obtained from published institutional sources where available: the OECD Affordable Housing Database for residential dwellings [72], the US Census Bureau ACS for manufactured housing [73], RVIA [74] for recreational caravans, UNHCR for emergency shelters [75], and Shoup [76], Barter [77] and the US FHWA NHTS [56] for vehicles. Where no published global figure was identified, an explicit rationale-based estimate was adopted and disclosed in Table 1. For each housing category j, the three deployability factors were computed as:

Equation 11

$$D_{low}(j) = \alpha_{low} \times v_j$$

$$D_{central}(j) = v_j + \beta_{central} \times (1 - v_j)$$

$$D_{high}(j) = v_j + \beta_{high} \times (1 - v_j)$$

Where v_j is the vacancy rate of category j; α_{low} is the accessibility factor representing the fraction of vacant stock that is realistically mobilizable once legal, logistical, and condition-related losses are accounted for; and $\beta_{central}$ and β_{high} are mobilisation coefficients representing the additional fraction of occupied stock that can be activated under voluntary, incentivized emergency requisitioning. The default values adopted in this study are α_{low} = 0.5, $\beta_{central}$ = 0.2 and β_{high} = 0.5. All deployability factors are capped at 100% to preserve physical consistency.

Three housing categories are governed by fixed overrides rather than by the standard formulation. Near-site company workforce housing is set to 100% across all scenarios because it is owned and operated by employers expressly for emergency workforce deployment. Hotels are capped at 50% across all scenarios because virus-prevention occupancy limits are assumed to halve usable capacity regardless of underlying vacancy. Office buildings are constrained to 30%, 40%, and 50% percent under the low, central and high scenarios, respectively, because unusable internal spaces and virus-prevention occupancy limits further reduce deployability beyond the bare office vacancy figure of approximately 17 percent.

For vehicles, the vacancy rate was defined as the proportion of the fleet surplus to a household’s essential transportation requirements, approximated by the share of vehicles that constitute a household's second or subsequent vehicle [56, 57]. A surplus-based vacancy rate of 45% was applied, based on reported multivehicle ownership shares [56, 57].

3.4.2. Anchor type B: Inventory and redundancy-based formulation for fixed amenities

Fixed basic amenities (heating systems, cooling systems, refrigerators, cooking stoves, kitchen sinks, and sanitary ware) cannot be deployed using the housing vacancy formulation because removing an amenity from an occupied dwelling either renders the dwelling uninhabitable or substantially degrades its habitability. The deployable stock of an amenity is therefore governed by two empirical quantities: the share of the inventory currently held outside occupied dwellings, for example, in manufacturer warehouses, in transit, or as commercial spare stock, and the share of dwellings that possess redundant units of the amenity that could plausibly be relinquished without depriving the household. For each amenity category j, the three deployability factors were defined as:

Equation 12

$$D_{low}(j) = i_j$$

$$D_{central}(j) = i_j + \gamma_{central} \times r_j$$

$$D_{high}(j) = i_j + \gamma_{high} \times r_j + \delta \times (1 - i_j - r_j)$$

where i_j denotes the warehouse, in-transit and spare-stock inventory rate (i.e., the mobilisation baseline); r_j denotes the household redundancy rate of category j (the share of dwellings possessing a second or third unit of the amenity); $\gamma_{central}$ and γ_{high} are the redundancy mobilisation coefficients under the central and high scenarios; and δ represents an additional incentivised extraction coefficient applied to the residual primary stock under full emergency mobilisation. The default values adopted in this study are $\gamma_{central}$ = 0.3, γ_{high} = 0.6, and δ = 0.05. The redundancy rate r_j varies markedly between categories, being lowest for heating systems and highest for sanitary ware, where dwellings with multiple bathrooms are common, so the upper bound of each amenity reflects the household redundancy structure rather than a single global ceiling.

The inventory rate of each amenity was derived from published manufacturing statistics. Finished-goods inventory held within the supply chain was expressed as a proportion of annual production, and after accounting for both manufacturer and downstream distributor stock, this proportion was found to correspond to approximately 5 weeks' worth of annual production across the relevant manufacturing sectors [58-60]. As the inventory rate in the present framework is defined relative to installed stock rather than annual production, this value was converted by dividing the inventory share of annual production by the assumed service life of each amenity, taken as fifteen years for heating systems, cooling systems, and refrigerators, and ten years for cooking stoves, kitchen sinks and sanitary ware [58-60]. This is a direct calculation rather than an independent approximation validated against separate data: the same 5-week supply-chain inventory share is applied to all six amenity categories, so the assumed service life is the only parameter that varies between categories. The resulting inventory rates are presented in Table 1.

An additional contribution to the deployable stock of each amenity arises from the global inventory of fully equipped temporary accommodation modules, comprising ready-and-equipped subcategories such as mobile homes, customised container housing, micro living pods, prefabricated foldable units, panelised modular buildings, hotels, vacant homes and seasonal homes, each of which is assumed to include its own working set of basic amenities. Because such modules are mobilizable irrespective of the scenario assumptions applied to their host categories, the per-country count of fully equipped accommodation units, denoted E_c, is added uniformly to each amenity category under all three scenarios. The total deployable stock of amenity j in country c therefore becomes:

Equation 13

$$D_{total}(j,s,c) = S_{j,c} \times D_{j,s} + E_c$$

where $S_{j,c}$ is the per-country stock of amenity j and $D_{j,s}$ is the deployability factor of amenity j under scenario $s \in$ {low, central, high}. The E_c term is identical across the three scenarios and is not added to the temporary-housing total, since the fully equipped modules are already counted within the 17 housing categories used to compute housing deployability.

The empirical parameters adopted for each category are summarised in Table 1. The resulting low, central and high deployability factors, computed directly from the equations above, are presented in Table 1 and are applied uniformly across all countries in the subsequent country-level analysis.

Table 1. Low, central, and high deployability factors adopted for each temporary housing and basic-amenity category.

Item	Variables		Deployability scenarios			Rationale/Reference
	v_j / i_j	r_j	Low	Central	High	
Mobile homes	6%	—	3.0%	24.8%	53.0%	Vacant share of manufactured-home stock [78]
Customized container housing	6%	—	3.0%	24.8%	53.0%	Analogy to modular-housing held stock prior to siting
Near-site company workforce housing	—	—	100%	100%	100%	Employer-owned, purpose-built for emergency workforce deployment
Recreational caravans	92%	—	46.0%	93.6%	96.0%	Median 30 days/year; approximately 92% idle [74]
Micro living pods	10%	—	5.0%	28.0%	55.0%	Analogy to prefabricated finished-goods held stock
Prefabricated foldable units	10%	—	5.0%	28.0%	55.0%	Analogy to prefabricated finished-goods held stock
Panelized modular buildings	10%	—	5.0%	28.0%	55.0%	Analogy to prefabricated finished-goods held stock
Emergency shelters	90%	—	45.0%	92.0%	95.0%	Assumed largely uncommitted contingency stock
Standard shipping containers	8%	—	4.0%	26.4%	54.0%	Buffer and repositioning stock idle in fleet circulation
Tents	40%	—	20.0%	52.0%	70.0%	Assumed held as stored reserve/surplus
Solar-powered reefer containers	10%	—	5.0%	28.0%	55.0%	Analogy to refrigerated-container idle/buffer share
Dockside bed ships / houseboats	20%	—	10.0%	36.0%	60.0%	Assumed idle/between-charter share
Vehicles	45%	—	22.5%	56.0%	72.5%	Surplus (second or subsequent) household vehicle share [56, 57]

Hotels, all types	—	—	50.0%	50.0%	50.0%	Capped at 50% due to assumed virus-prevention occupancy limits(every-other-room spacing)
Office buildings	—	—	30.0%	40.0%	50.0%	Assumed usable share, reduced for unusable internal space and occupancy limits
Vacant homes	—	—	50.0%	75.0%	100%	Assumed available share of unoccupied dwellings, discounted for uninhabitable units
Seasonal homes	—	—	40.0%	65.0%	90.0%	Assumed available share of seasonally unoccupied dwellings
Heating systems	0.64%	30%	0.6%	9.6%	22.1%	Assumed redundant/spare share of installed stock
Cooling systems	0.64%	25%	0.6%	8.1%	19.4%	Assumed redundant/spare share of installed stock
Refrigerators	0.64%	35%	0.6%	11.1%	24.9%	Assumed redundant/spare share of installed stock
Cooking stoves	0.96%	25%	1.0%	8.5%	19.7%	Assumed redundant/spare share of installed stock
Kitchen sinks	0.96%	40%	1.0%	13.0%	27.9%	Assumed redundant/spare share of installed stock
Sanitary ware	0.96%	50%	1.0%	16.0%	33.4%	Assumed redundant/spare share of installed stock

3.5. Validation methodology

Since no single published dataset reports the existing stock of temporary-housing units and basic amenities at the global, multicategory level adopted in this study, the present estimates cannot be validated against a directly comparable dataset. A like-for-like benchmark was therefore constructed from independent, authoritative data for the subset of categories and high-income countries where reliable unit-level records are publicly available. High-income economies were selected deliberately, as their market and ownership statistics are the most complete and consistently reported, which keeps the validation internally consistent and avoids the larger reporting gaps that affect emerging markets.

The estimates produced here represent the total stock accumulated over each product's service life. The independent sources, by contrast, report annual unit shipments or sales rather than accumulated stock. To place the two on a comparable basis, the reported annual figures were summed over the same service-life window used in the estimation. This survival-from-shipments principle—reconstructing in-use stock by accumulating historical shipments over the product lifetime— is an established approach used by national agencies for appliance-stock estimation, and mirrors the logic underlying the present model. For a given category and country, the accumulated benchmark stock S_c is obtained by summing the reported annual demand D_t over the service life *L*, ending in the reference year *Y*:

Equation 14

$$S_c = \sum D_t \quad , \; t = Y - L + 1 \ldots Y$$

where D_t is the independently reported number of units sold or shipped in year t, L is the assumed service life (within the 10–15-year range), and Y is the reference year (2024). Evaluating the sum at the lower and upper bounds of L yields the benchmark range reported below, while the twelve-year midpoint provides a central value. The agreement between the current estimate *E* and the benchmark Sc is expressed as the relative deviation δ:

Equation 15

$$\delta = \frac{(E - S_c)}{S_c} * 100$$

3.6. Vehicle-conversion labour requirements

For a representative midsize cargo van, the labor requirement is estimated at 18 person-hours per vehicle, broken down as follows: 4 person-hours for cleaning and seat removal (if needed), 8 person-hours for thermal insulation of the walls, ceiling, and floor, and 6 person-hours for installing ventilation, a bed platform, window covers, and basic lighting. The total labor input required to convert the vehicles can be expressed as:

Equation 16

$$L_{total} = N_v \times (t_c + t_i + t_{inst})$$

where N_v is the number of vehicles, t_c is the time for cleaning and seat removal, t_i is the time for insulation, and t_{inst} is the time required for installation. To complete these conversions within the targeted one-month deployment window under crisis conditions, assuming 30 working days and 24-hour operation in three 8-hour shifts, the required workforce in person-months is calculated as:

Equation 17

$$PM = \frac{L_{total}}{30 \times 24}$$

3.7. Controlled sharing protocol scaling methodology

Under this protocol, the effective capacity of each equipment category was scaled according to daily operating windows and disinfection time. For example, a cooking stove with a 45-minute cooking period plus a 15-minute disinfection period yields a one-hour cycle, allowing eight workers to share the unit over an 8-hour operating window. Similar cycle-based multipliers were derived for kitchen sinks, showers, and other amenities. The general scaling factor for each amenity type can be expressed as:

Equation 18

$$Sharing\ Capacity = Base\ Stock \times \left(\frac{Daily\ Operational\ Hours}{Cycle\ Time\ per\ Worker}\right) \times Sharing\ Efficiency\ Factor$$

where the sharing-efficiency factor accounts for the disinfection interval and scheduling constraints required for safe use. This approach effectively multiplies the usable capacity while maintaining airborne and contact transmission controls.

4. Results and discussions

4.1. Validation of the stock's estimations

The independent benchmark and the relative-deviation calculation used to validate the stock estimates are described in Section 3.5. Table 2 summarizes the current estimates alongside independently derived benchmarks. For each category, the service life used and corresponding benchmark stock are reported, together with the resulting deviation. As shown in Table 2,across all four categories, the current estimates are reasonably close to the benchmarks, with deviations of −9%, +3%, +25%, and +10% for air conditioners, refrigerators, recreational caravans, and shipping containers, respectively.

Table 2. Validation of the current stock estimates against independent benchmarks derived by accumulating reported annual unit sales over each product's service life.

Category	Geography	Current estimate (units)	Lifespan (years)	Benchmark stock (units)	Deviation	Reference
Air conditioners	USA	130,592,561	10	≈ 144,000,000	−9%	Ref [63]
Refrigerators	USA	139,162,386	15	≈ 135,000,000	+3%	Ref [64], [65]
Recreational caravans	Global	15,500,000	20	≈ 12,000,000	+25%	Ref [66]
Shipping containers	Global	48,000,000	15	≈ 44,000,000	+10%	Ref [67]

Figure 1 presents the validation of the current stock estimates against independent benchmarks for four representative categories representing the housing and amenity components of the inventory: air conditioners and refrigerators for the United States, and recreational caravans and shipping containers at the global scale. For each category, the orange bar denotes the current estimate and the blue bar the benchmark derived by accumulating independently reported annual unit sales over each product's service life; values are normalized to the benchmark (100) to permit comparison across categories of differing magnitude. The percentage above each pair shows the relative deviation of the estimate from the benchmark. All four estimates fall within 25% oftheir respective benchmarks, with deviations of −9%, +3%, +25%, and +10%, indicating close agreement between the present estimates and independently observed quantities.

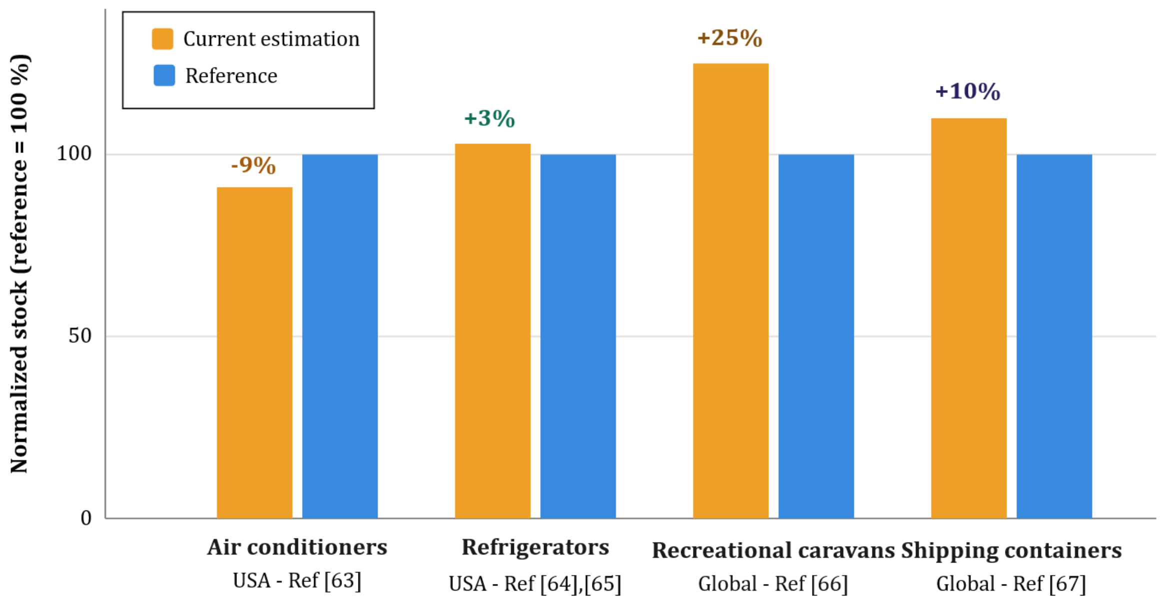


Figure 1. Comparison of current stock estimates with independent benchmarks.

4.2. Inventory, shortfalls, and coverage of temporary housing for workers

The total populations of workers requiring protection were first quantified at the global scale based on essential and vital worker counts calculated by Ng et al. [14]. Based on their estimates, and after removing subsistence farmers and market-oriented farmers likely to live on their farms, approximately 595 million VW and 1.3 billion EW are expected to require emergency worker housing in an extreme pandemic. The number of EW requiring housing relative to the total population varies markedly by country, with higher-income countries tending to have higher relative housing requirements than lower-income countries (See Figure A in Appendix). This contrasts with overall EW and VW, which tend to make up a higher fraction of the population in lower-income countries, as reported by Ng et al. [14]. This difference is due in part to the higher prevalence of smallholder farming in lower-income nations, with these workers not included in emergency housing requirements. This variation reduces for VW and is far from universal, however, with some of the highest relative EW and VW housing requirements observed in upper-middle income countries like Ukraine, Peru, and Mexico.

To accommodate these workers on site and break the workplace-home transmission chain, 17 categories of low-tech, low-cost, and rapidly deployable temporary housing modules were evaluated. These modules were selected and categorised according to their level of readiness for immediate use: "ready-and-equipped," "need to be erected and equipped," and "need to be equipped only." In addition, underutilized building stocks such as hotels, office buildings, vacant homes, and seasonal homes were also included. All categories were chosen for their potential to be deployed within one month using existing global inventories. Global stocks of these modules were estimated from 2024 market data, yielding a combined total of roughly 988 million units, when all sources are considered (Table 3).

According to Table 3, tents constitute the single largest share by a considerable margin, providing the bulk of low-cost, highly scalable capacity that can be deployed almost anywhere with minimal preparation. In contrast, modular solutions such as mobile homes, customized containers, and panelized buildings provide more structured and comfortable accommodation but make up a much smaller portion of the total stock. Underutilized buildings, including hotels, office spaces, vacant homes, and seasonal residences, add a significant complementary volume, taking advantage of existing infrastructure that requires relatively little modification. Vehicles, including vans and school buses, further expand the pool with a large but more basic form of shelter. Thus, the inventory is heavily dominated by simple, high-volume options like tents and vehicles, while more conventional modular buildings are considered high-quality housing.

Table 3. Global availability of temporary housing modules.

Type of temporary housing	Estimated global stock
Mobile homes	9M
Customized container housing	18M
Near-site company workforce housing	12.5M
Recreational caravans	15.5M
Micro living pods	0.086M
Prefabricated foldable units	14.5M
Panelised modular buildings	23.5M
Emergency shelters	0.081M

Standard shipping containers	48M
Tents	208M
Solar-powered reefer (refrigerated) containers	0.264M
Dockside bed ships/houseboats	0.335M
Vehicles	284M
Hotels (all types)	41M
Office/commercial buildings	81M
Vacant homes	185M
Seasonal homes	43M
Total	988M

The geographical distribution of temporary housing shortages, mapped under the theoretical full-availability baseline for both worker groups, is provided in Appendix (See Figure B). The seventeen temporary-housing categories differ substantially in the standard of accommodation they provide, and it is therefore useful to distinguish higher-quality, self-contained housing from lower-quality options offering only basic shelter. In this paper, low-quality housing comprises emergency shelters, standard shipping containers, tents, solar-powered reefer containers, and converted vehicles, while the the remaining categories are considered as high-quality housing. The housing-shortage maps presented in Figure B in Appendix classify each country on this basis into three groups: those able to accommodate their workers using high-quality housing alone, those that avoid a shortage only once lower-quality housing is also included, and those that remain in deficit even when the entire housing stock is combined. For the VW group, a substantial number of countries, concentrated in North America, Europe, parts of South America, and Oceania, can be accommodated using high-quality housing alone, while many others, including much of Asia and parts of Latin America, avoid a shortage only by drawing additionally on lower-quality housing such as tents and vehicles; a further group, located predominantly across sub-Saharan Africa, the Middle East, and South Asia, remains in deficit even when all housing types are counted together. For the EW group, the position is markedly more constrained: the set of countries able to rely on high-quality housing alone shrinks to a small number of mostly European states, and the majority of countries, including most of Africa, South and Southeast Asia, and South America, remain in shortage even after lower-quality housing is fully incorporated. This pattern indicates that the apparent adequacy of the aggregate housing stock depends heavily on the availability of basic, lower-quality shelter, and that for the broader essential workforce a large number of countries cannot meet demand from any combination of existing housing.

Regarding the conversion the existing vehicles into basic habitable shelters, a set of minimal but essential modifications is required. These conversions focus on thermal comfort, moisture control, privacy, sleeping space, and basic utilities, while cooking, sanitation, and showering facilities are assumed to be provided through external shared infrastructure. The labour-requirement calculation for these conversions is described in Section 3.6.

This metric, expressed as the required number of vehicle-conversion workers per 100,000 members of the labor force, together with the associated shortages of thermal-insulation materials, is mapped (See Figures C and D, respectively, presented in the Appendix). All countries possess sufficient labor to complete the vehicle conversions within the one-month timeframe, although the relative burden varies considerably: in the worst case, San Marino would require approximately 1,066 workers per 100,000 labour force, equivalent to about 1% of its total labour force. Several high-income countries show a proportionally higher burden owing to their larger vehicle fleets relative to labour-force size, whereas countries with smaller vehicle stocks face a lighter demand. For thermal insulation, almost all countries have approximately sufficient material stock, with only the United States and Brazil facing considerable shortages of 24% and 60%, respectively.

4.3. Global inventory, shortfalls, and controlled sharing protocol of basic amenities

Following the assessment of temporary housing capacity, attention turned to ensuring that the available shelters could be rendered habitable for essential worker groups under extreme-pandemic conditions. The minimum basic amenities required for comfort, sanitation, food preparation, and thermal control were therefore quantified at both global and national scales. Table 4 provides the detailed breakdown of the total number of individual basic amenities available worldwide in 2024. The equipment was grouped into six functional categories to facilitate comparison against worker populations. Table 4 also presents the aggregated stocks for each category in 2024.

The national-level figures for heating and cooling systems are presented in Figures E and F, respectively, in the Appendix These figures represent the maximum theoretical pool that could be mobilised for on-site worker accommodation. When benchmarked against the EW population of 1.3B, heating and cooling systems were found to exceed the per capita requirement globally. Heat pumps, which serve both heating and cooling functions, were included in both the heating and cooling equipment categories. In contrast, refrigerators, cooking stoves, kitchen sinks, and sanitary ware fell substantially short of the worst-case demand. This imbalance indicates that while thermal comfort could theoretically be assured for the entire essential workforce, critical gaps exist in food storage, meal preparation, and personal hygiene infrastructure. However, the shortfall in kitchen sinks is among the most readily mitigated, since a basic hand-washing station can be improvised at low cost from a plastic container and a refillable water vessel, whereas the deficits in food storage, cooking, and sanitary ware are considerably harder to address through improvisation. In this paper, toilets and showers were treated as separate inventory items in Table 4, while being referred to collectively as sanitary ware in the discussion. For the aggregated sanitary ware estimate, the lower available stock of the two items was used as the limiting value, since both items would be required for complete sanitation provision.

Table 4. Estimated global stocks of individual basic amenities and aggregated category totals in 2024.

<table>
<tr><th>Category</th><th>Type of equipment</th><th>Estimated stock (units)</th><th>Aggregated stocks (units)</th></tr>
<tr><td rowspan="5">Heating systems</td><td>Electrical space heaters</td><td>493M</td><td rowspan="5">1.7B</td></tr>
<tr><td>Gas space heaters</td><td>310M</td></tr>
<tr><td>Indirect oil-fired air heaters</td><td>200M</td></tr>
<tr><td>Furnaces</td><td>7.5M</td></tr>
<tr><td rowspan="2">Heat pumps</td><td rowspan="2">680M</td></tr>
<tr><td rowspan="3">Cooling systems</td><td rowspan="3">2.3B</td></tr>
<tr><td>Air conditioners</td><td>453M</td></tr>
<tr><td>Cooling fans</td><td>1.2B</td></tr>
<tr><td>Refrigerator</td><td>Household refrigerators</td><td>917M</td><td>990M</td></tr>
</table>

	Mini fridges	73M	
Cooking stove	Portable cooking stoves	205M	205M
Kitchen sink	Portable kitchen sinks	2M	107M
	Portable handwash stations	12.5M	
	Dishwashers	93M	
Sanitary ware	Portable showers	4.5M	4.5M
	Portable toilets	136M	

To make the shelters operational within the required one-month deployment window, the availability of skilled labour for plumbing and electrical installation was also evaluated, with the country-level maps provided in Appendix (see Figure G). Electrician availability was generally closer to sufficiency than plumber availability: major economies such as the United States, Canada, Russia, and China faced mean shortages of approximately 40% for electricians and 70% for plumbers, while Australia and India possessed sufficient electricians but remained constrained by plumber availability. Most remaining countries showed adequate labor supply in both trades.

Before applying the controlled sharing protocol, it is good to mention that existing global stocks in the world can meet the worker needs to some extent. Table 5 outlines the baseline coverage achieved by the existing temporary-housing and basic-amenity stocks before applying any sharing protocols. In terms of housing, the results show that current temporary housing capacity can accommodate the entire VW group and 76% of the EW group. In terms of basic amenities, even in this full-availability baseline, the existing global inventory exceeds the full requirement for both worker groups in heating and cooling systems. The remaining categories fall well short of EW demand. The most severe shortfall is associated with sanitary ware, which covers 0.8% of VW and 0.3% of EW. This indicates the need for the controlled sharing protocol to try to fully cover the worker's basic needs.

Table 5. Baseline coverage (percentage of demand met) for housing and basic amenities relative to VW and EW, computed on a global-aggregate basis (assuming an open worldwide pool of stock) before any controlled sharing protocol or addition of ready-and-

equipped modules. Values above 100% indicate a surplus; values below 100% indicate a shortfall.

Housing/equipment	Relative to VW (%)	Relative to EW (%)
Housing	166	76
Heating systems	285	130
Cooling systems	386	176
Refrigerator	166	76
Cooking stove	34	15
Kitchen sink	18	8
Sanitary ware	0.8	0.3

A controlled sharing protocol was therefore developed to bridge the identified equipment gaps without requiring new manufacturing. In this study, some of the proposed temporary-housing are classified as ready-and-equipped. These include mobile homes, customized container housing, near-site company workforce housing, recreational caravans, micro-living pods, prefabricated foldable units, hotels, vacant homes and panelised modular buildings. Thus, for controlled sharing purposes, these ready-and-equipped housing units are first added to the baseline stock, contributing an additional 448 million fully equipped units. Each ready-and-equipped housing unit is assumed to accommodate one essential worker. For all remaining shelters, a controlled sharing protocol is applied under strict safety measures. The protocol incorporated a 15-minute disinfection interval after each use, along with a scheduled rotation system that prevented simultaneous occupation of shared spaces such as kitchens [68].

The scaling calculation used to convert base stock into shared operational capacity is described in Section 3.7. The global shortages of basic amenities for the two labour-force groups after applying a controlled sharing protocol are presented in Figure 2. As shown in Figure 2, adding the ready-and-equipped modules and applying the controlled sharing protocol increased coverage of basic amenities. Kitchen sinks met the full VW and EW requirements, with surpluses of 264% and 67%, respectively. Cooking stoves exceeded the requirements of both groups, with a 250% surplus relative to VW and a 61% surplus relative to EW. Sanitary ware also shifted to surplus, exceeding VW demand by 186% and EW demand by 31%. Refrigerators also showed surplus among the basic amenities, exceeding VW demand by 295% and EW demand by 82%. Thus, at the global level, where stock is treated as a single open-trade pool, the controlled sharing protocol converts most amenity deficits to surpluses.

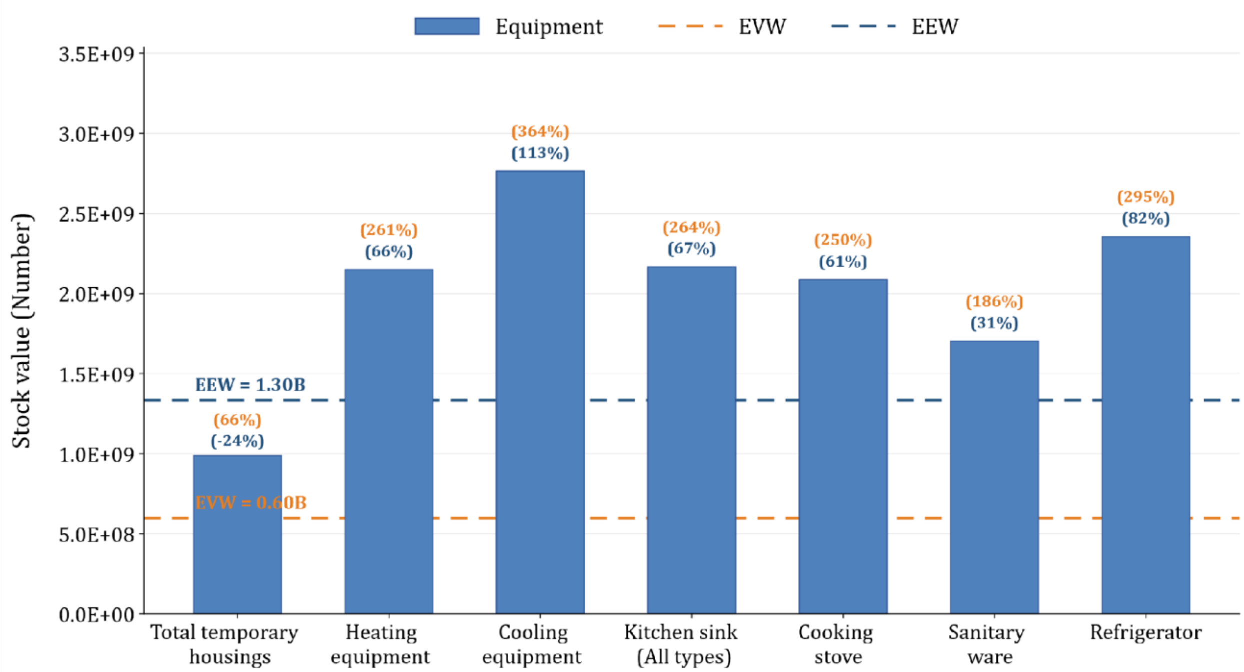


Figure 2. Global shortages of temporary housing and basic amenities for the VW and EW groups under the controlled sharing protocol.

4.4. Sensitivity to deployable-stock availability

To test the robustness of the baseline stock estimates, low, central, and high deployability scenarios were applied to all temporary-housing and basic-amenity categories. These scenarios represent uncertainty in the share of estimated stocks that could realistically be mobilised during an extreme pandemic once constraints such as private ownership, existing occupancy, legal access, commercial commitments, emergency reservation, and the fixed nature of many installed assets are considered. Thus, the scenario analysis shifts the interpretation of the stock estimates from a single full-availability inventory estimate to a planning range of practically deployable capacity.

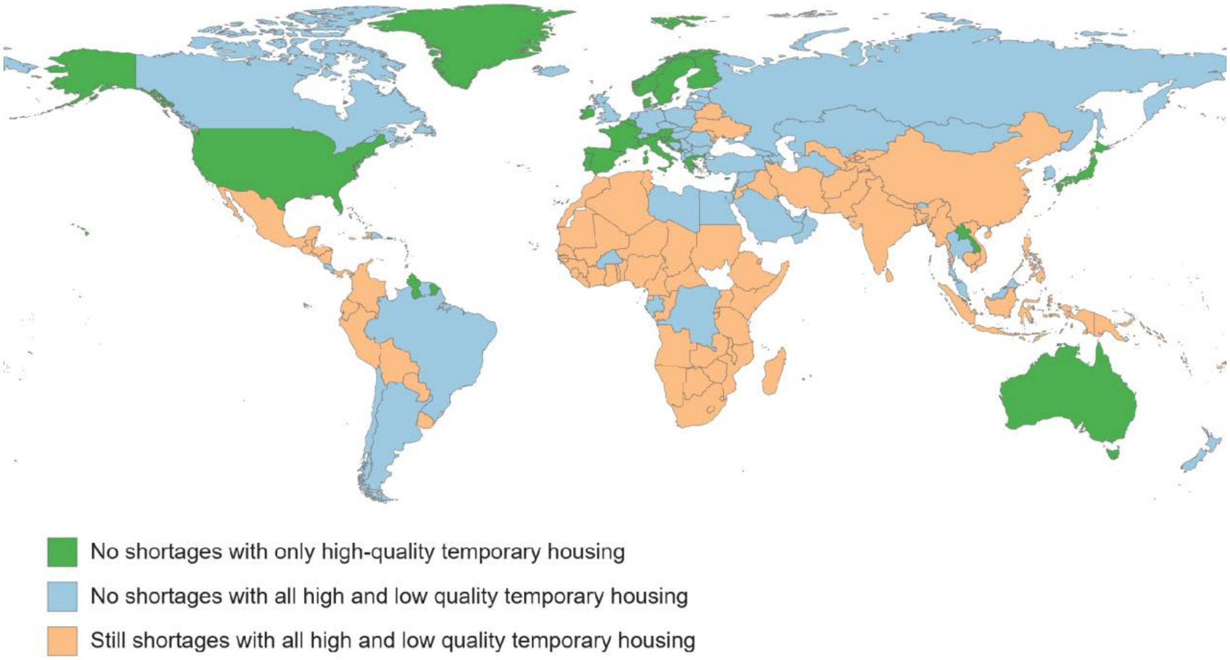
This refinement is particularly important for interpreting the results of the controlled sharing protocol. Sharing reduces the quantity of amenity equipment required to serve a given worker population, but it does not eliminate the need for a sufficient deployable stock in the first place. Consequently, categories that remain sufficient even under low deployability can be considered relatively robust, whereas categories that become sufficient only under central or high deployability should be regarded as more conditional. Categories that remain insufficient even under high deployability may represent priority areas for preparedness planning.

For illustration, this section and Figures 4–12 report detailed national results for 12 selected economies: the United States, Canada, Brazil, Germany, the United Kingdom, Russia, China, India, Japan, Australia, Singapore, and Iran; full results for all 199 countries are provided in the Supplementary Material. Figure 3 maps the national-level shortages of temporary housing under the central deployability scenario for the VW and EW groups. Relative to the VW group (Figure 3a), 102 of 199 countries (51%) achieved full coverage, with surpluses that are frequently large in high-income economies; for instance, the United States, Australia, Japan, and Singapore record surpluses exceeding 160% relative to their VW requirements, reflecting substantial estimated stocks of vacant dwellings, hotels, vehicles, and seasonal housing relative to a comparatively small vital-worker population. The remaining 97 countries (49%), including several populous ones, nevertheless remain in deficit even for the VW group, most notably India (−60%), China (−14%) and Iran (−4%), where large workforces are not offset by proportionally large estimated stocks of potentially repurposable housing. When the same stock is assessed relative to the much larger EW group (Figure 3b), the spatial pattern becomes markedly less favourable, and shortages become considerably more widespread. Brazil and Iran display deficits of around −50%, and even the United Kingdom and Japan, which fully satisfy VW demand, show modest EW shortfalls (−15% and −3%, respectively). This contrast confirms that national temporary-housing adequacy is highly sensitive to the breadth of the protected population, and that coverage achievable for vital workers does not extend to the full essential workforce in many populous nations.

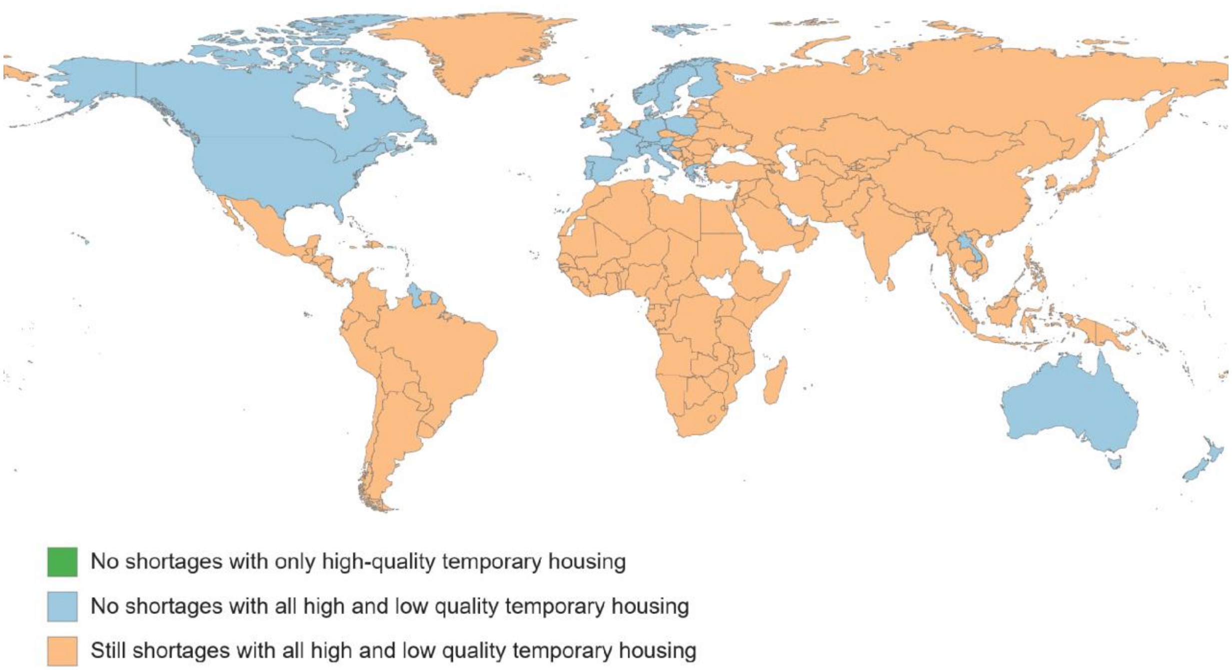
These coverage estimates are, however, sustained in large part by the lower-quality segment of the housing stock, and the picture changes substantially once housing quality is taken into account. When coverage is restricted to higher-quality housing alone, the central-scenario position deteriorates markedly; the median national shortfall relative to the VW group widens from approximately balanced coverage to about −48%, and relative to the EW group from around −53% to −77%, while the number of countries able to fully accommodate the VW group falls from 102 to 41 and, for the

EW group, from 33 to only 3 (of 199 countries). This indicates that the apparent adequacy of the aggregate housing stock is sustained in large part by lower-quality, high-volume options, particularly tents and vehicles, which account for a large share of the inventory. A tiered interpretation is therefore appropriate, in which a limited tier of high-quality accommodation is supplemented, where necessary, by a much larger tier of basic shelter, with the balance between the two determining the realistic standard of isolation that can be provided.

This tiered structure has direct implications for decision-making. Where higher-quality accommodation is insufficient, policymakers may need to rely on the lower-quality tier to close the gap, accepting a reduced standard of comfort in exchange for greater isolation capacity. In such cases, self-contained units such as converted vehicles offer a practical advantage, since an individual worker can be isolated within a discrete, independently ventilated space and supported through external provisioning, such as food delivery, thereby avoiding shared circulation and contact. By contrast, repurposing large commercial buildings such as office blocks for isolation is more demanding, because partitioning open-plan interiors into independently controlled, positive-pressure compartments to prevent cross-contamination is technically difficult and resource-intensive. Consequently, although commercial buildings contribute meaningfully to the aggregate stock, independently enclosed units are likely to provide potentially more practical isolation per unit of effort, a distinction that is relevant when prioritising which categories of stock to mobilise first.



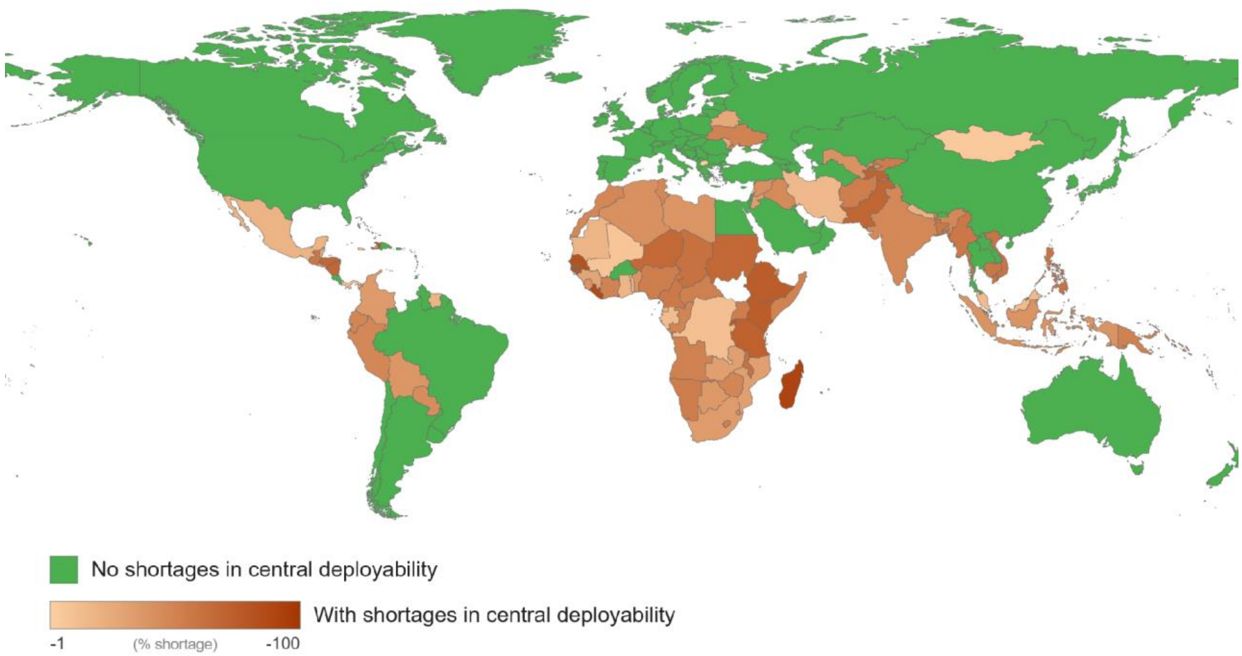
a) Comparison with VW group



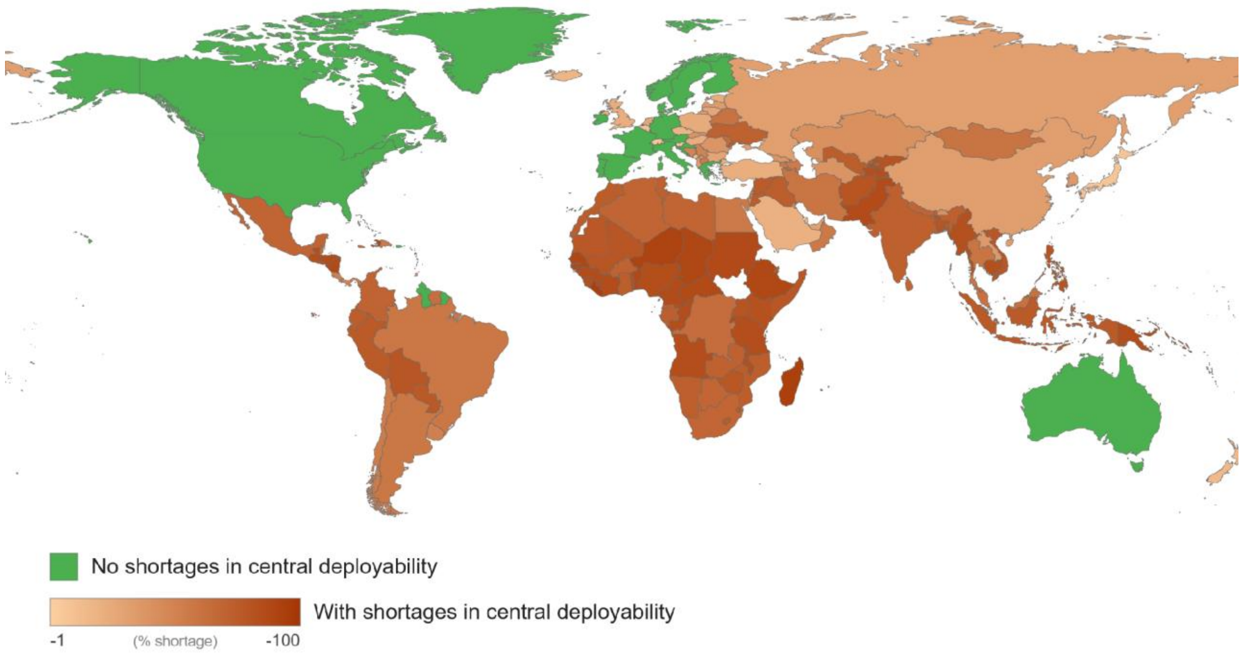
b) Comparison with EW group

Figure 3. Nation-level shortages of temporary housing under the central deployability scenario for (a) VW and (b) EW.

In addition to housing units, basic amenities are important to make them habitable for workers. Figure 4 presents the central-scenario shortages of heating systems at the national level. A group of 12 high-output economies was selected to highlight the country-by-country results: the United States, Canada, Brazil, Germany, the United Kingdom, Russia, China, India, Japan, Australia, Singapore, and Iran. Relative to the VW group (Figure 4a), heating provision is sufficient in 10 of the 12 selected economies, with only India (−46%) and Iran (−16%) among the selected economies remaining in deficit; the remaining countries hold surpluses, which are particularly large in colder, higher-income economies where installed heating stock per capita is high. The picture changes substantially when heating stock is benchmarked relative to the EW group (Figure 4b). Under this broader demand, deficits emerge across a much larger set of countries, including China (−33%), Russia (−32%), the United Kingdom (−23%), and Japan (−7%), while India and Iran deepen to −72% and −59%, respectively. Brazil exhibits one of the largest national shortfalls at −58%, reflecting both a large essential workforce and a comparatively modest estimated heating-system stock in a predominantly warm climate. The juxtaposition of the two maps indicates that although heating is among the better-resourced amenities at the global scale, its national adequacy for the full essential workforce is far from universal and is concentrated in a limited number of high-income, temperate-climate countries.



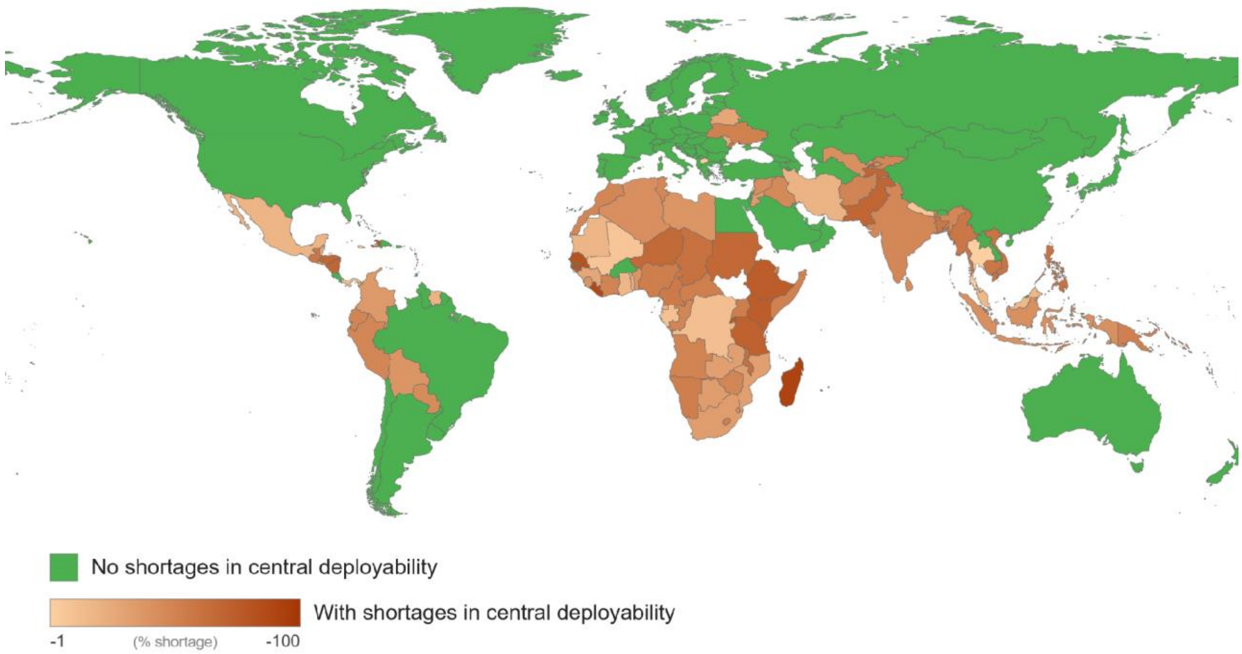
a) Comparison with VW group



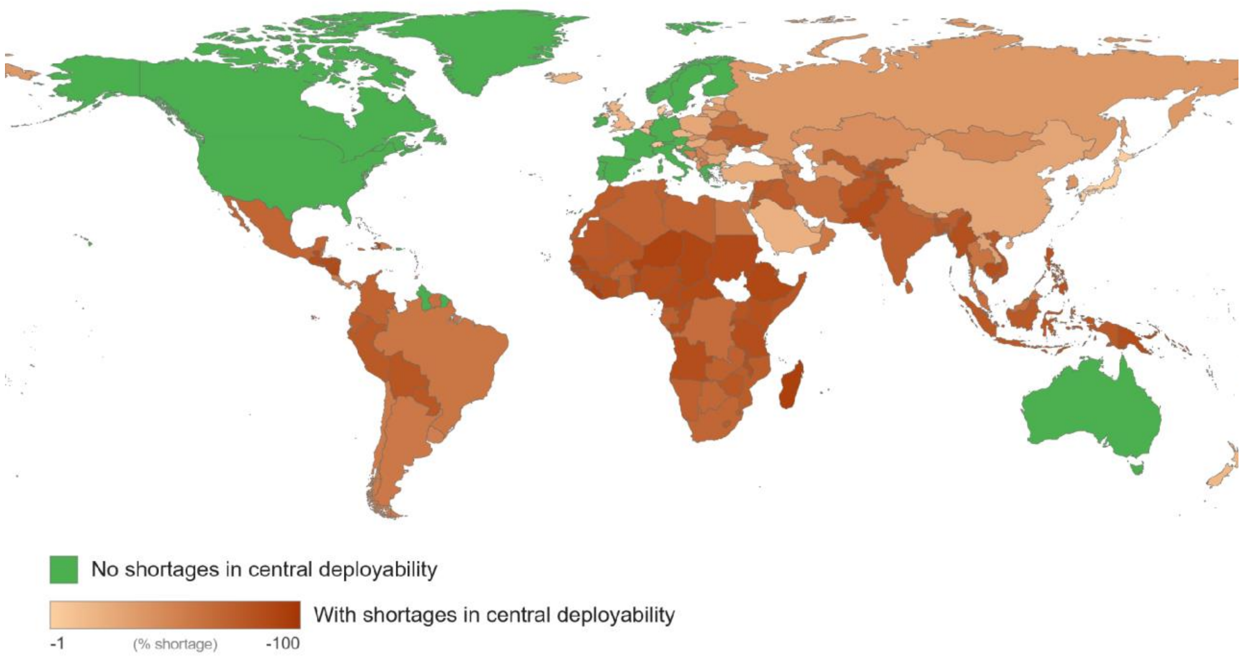
b) Comparison with EW group

Figure 4. Nation-level shortages of heating systems under the central deployability scenario, with the controlled sharing protocol applied.

The national distribution of cooling-system shortages under the central scenario is shown in Figure 5. Relative to the VW group (Figure 5a), cooling provision is sufficient in 10 of the 12 selected countries, with only India (−48%) and Iran (−20%) remaining materially short. When assessed relative to the EW group (Figure 5b), however, shortages become more widespread. Russia (−36%), China (−28%) and the United Kingdom (−18%) shift into deficit, Japan falls marginally short (−2%), and India and Iran register severe shortfalls of −73% and −61%, respectively. Brazil records a deficit of −59% despite its warm climate, indicating that the absolute size of its essential workforce outweighs its installed cooling capacity. As with heating, the comparison demonstrates that the comfortable global surplus in cooling is unevenly distributed and does not translate into national-level adequacy for the broader worker group in several of the selected economies.



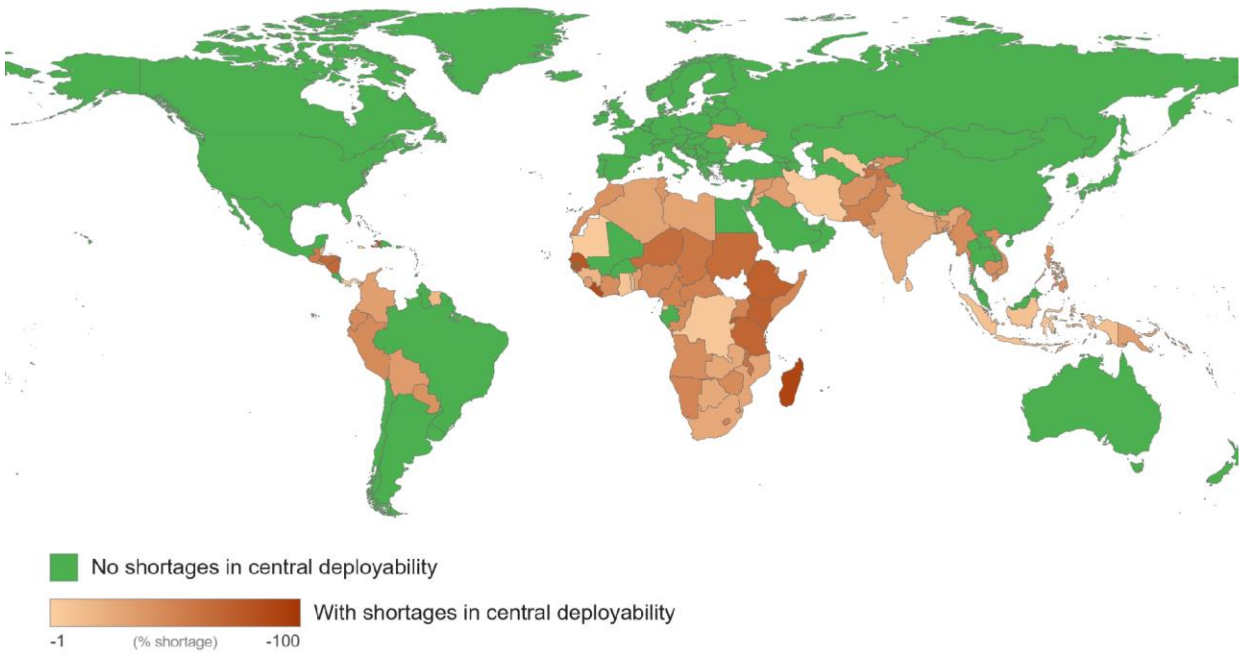
a) Comparison with VW group



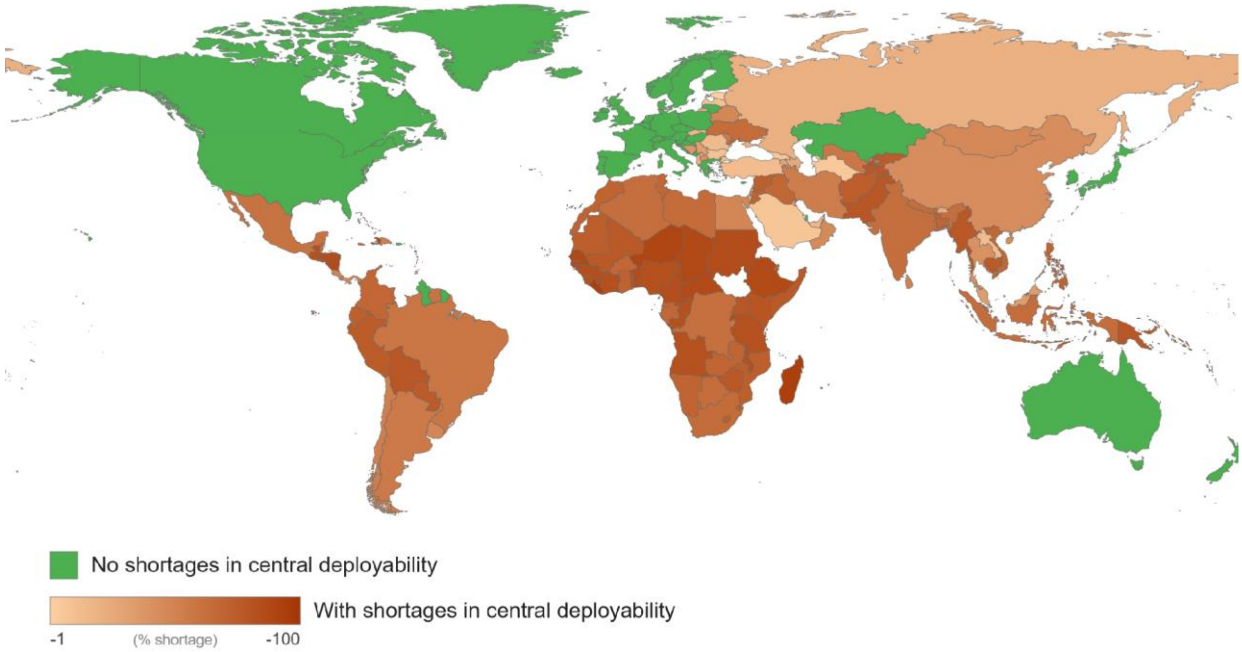
b) Comparison with EW group

Figure 5. Nation-level shortages of cooling systems under the central deployability scenario, with the controlled sharing protocol applied.

Figure 6 illustrates the central-scenario shortages of refrigerators across countries. For the VW group (Figure 6a), refrigerator coverage is sufficient in 10 of the 12 selected economies, with only India (−28%) and Iran (−5%) remaining in deficit, while higher-income economies such as Singapore, Australia and Germany display very large surpluses. Relative to the EW group (Figure 6b), the deficits broaden, with India (−63%), Brazil (−59%), Iran (−54%), and China (−44%) all recording substantial shortfalls, and Russia falling short by −21%. Nevertheless, a few high-income countries, including the United States, Germany, Australia, Singapore, and Japan, retain positive coverage for the EW group, indicating that food-storage capacity is comparatively greater in these economies. The results identify refrigeration as a category in which national disparities are pronounced, with adequacy for the essential workforce confined largely to wealthier nations.



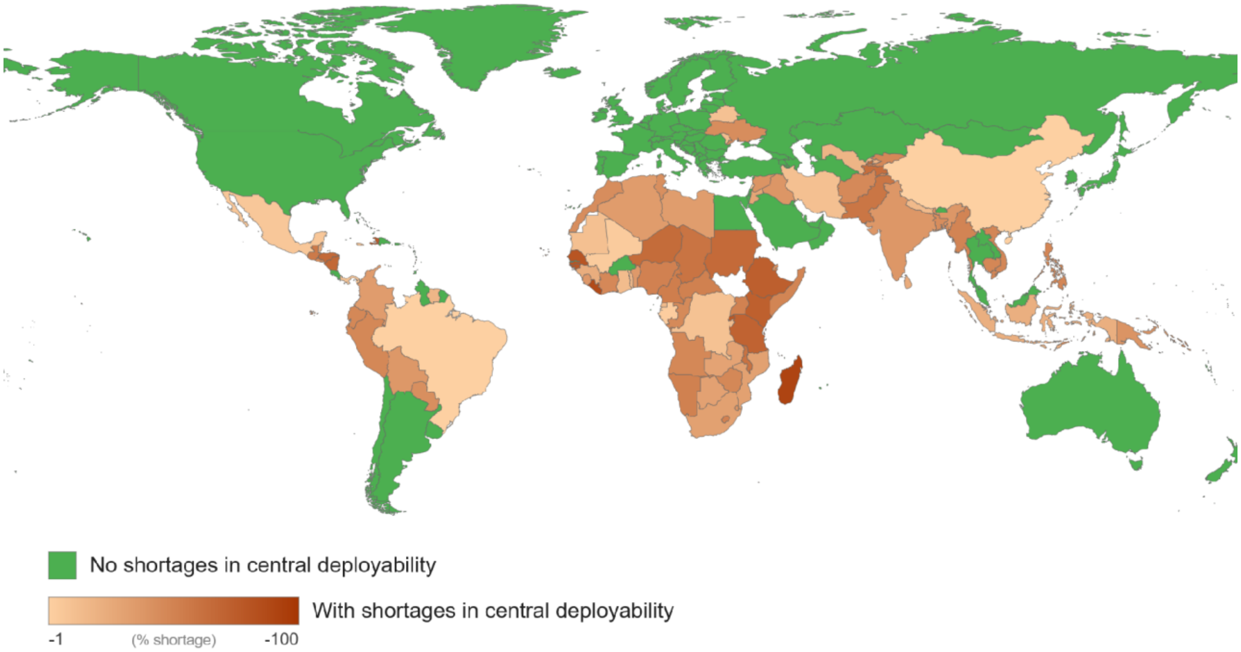
a) Comparison with VW group



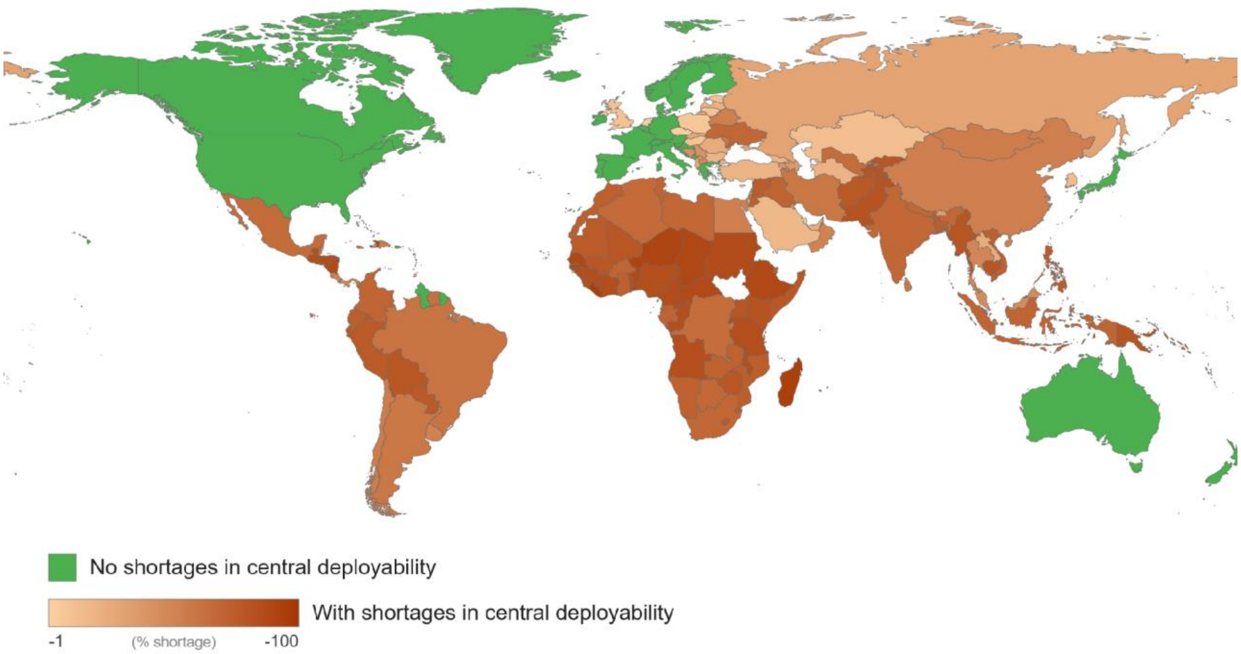
b) Comparison with EW group

Figure 6. Nation-level shortages of refrigerators under the central deployability scenario, with the controlled sharing protocol applied.

The central-scenario shortages of cooking stoves are mapped in Figure 7. Relative to the VW group (Figure 7a), cooking-stove provision is among the most constrained amenity categories, with India (−38%), Iran (−11%), China (−0.2%) and Brazil (−0.5%) in deficit, the latter two only marginally so. Relative to the EW group (Figure 7b), cooking stoves emerge as a critical bottleneck: several selected countries fall into substantial deficit, including India (−68%), Brazil (−60%), Iran (−57%), China (−52%) and Russia (−30%), with the United Kingdom also short by −10%. The limited installed base of portable cooking equipment relative to the size of the essential workforce underlies this pattern. These findings reinforce the global-scale result that meal-preparation infrastructure is among the least adequately provisioned amenities and would require targeted procurement, stockpiling, or other alternative cooking arrangements to support full essential-worker accommodation.



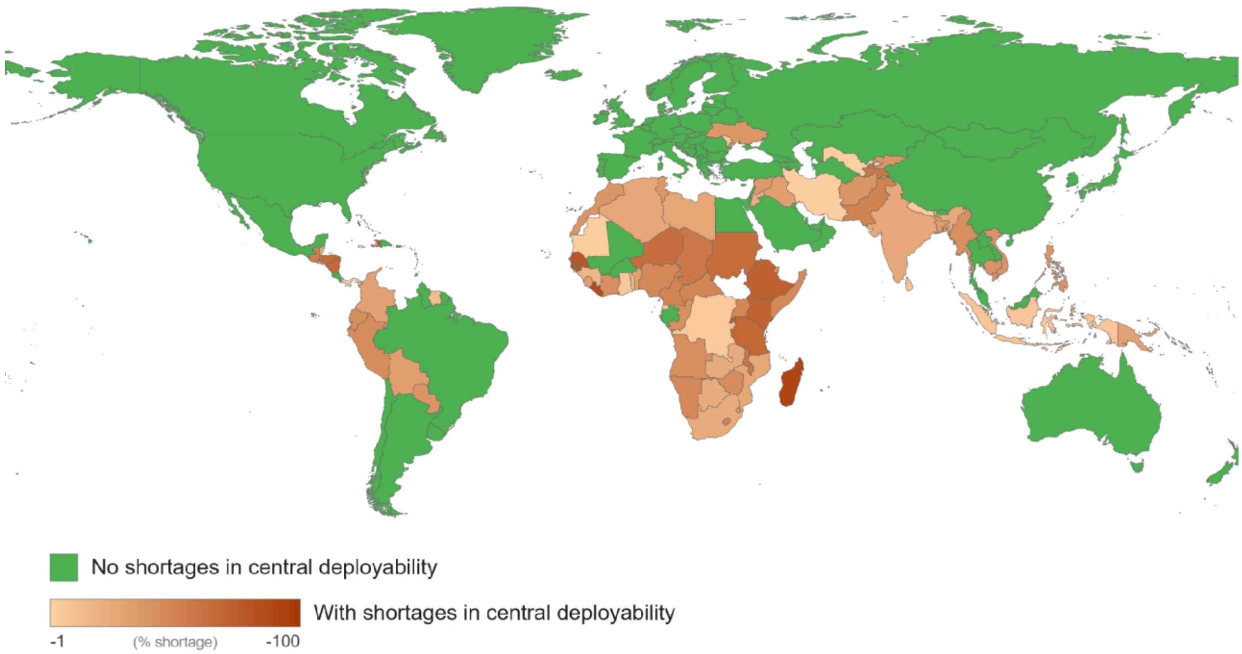
a) Comparison with VW group



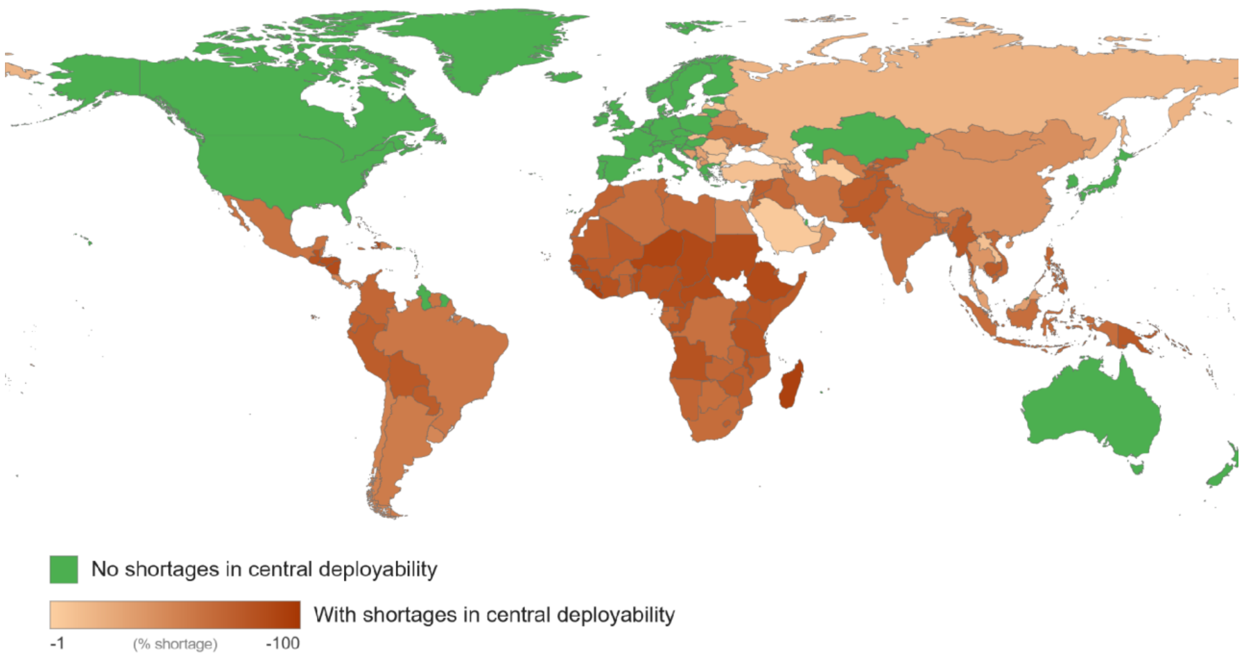
b) Comparison with EW group

Figure 7. Nation-level shortages of cooking stoves under the central deployability scenario, with the controlled sharing protocol applied.

Figure 8 shows the national shortages of kitchen sinks under the central scenario. For the VW group (Figure 8a), coverage is sufficient in 10 of the 12 selected economies, with deficits confined to India (−26%) and Iran (−3%), and large surpluses recorded in high-income nations. When measured against the EW group (Figure 8b), the deficits widen to include India (−62%), Brazil (−58%), Iran (−53%), China (−43%), and Russia (−19%), although the United States, Germany, the United Kingdom, Australia, Singapore, and Japan retain positive coverage. As noted in the global analysis, the kitchen-sink shortfall may be relatively easier to mitigate , since basic hand-washing and food-preparation stations can be improvised at low cost; the national maps nonetheless highlight the same concentration of unmet need in the most populous lower- and middle-income countries.



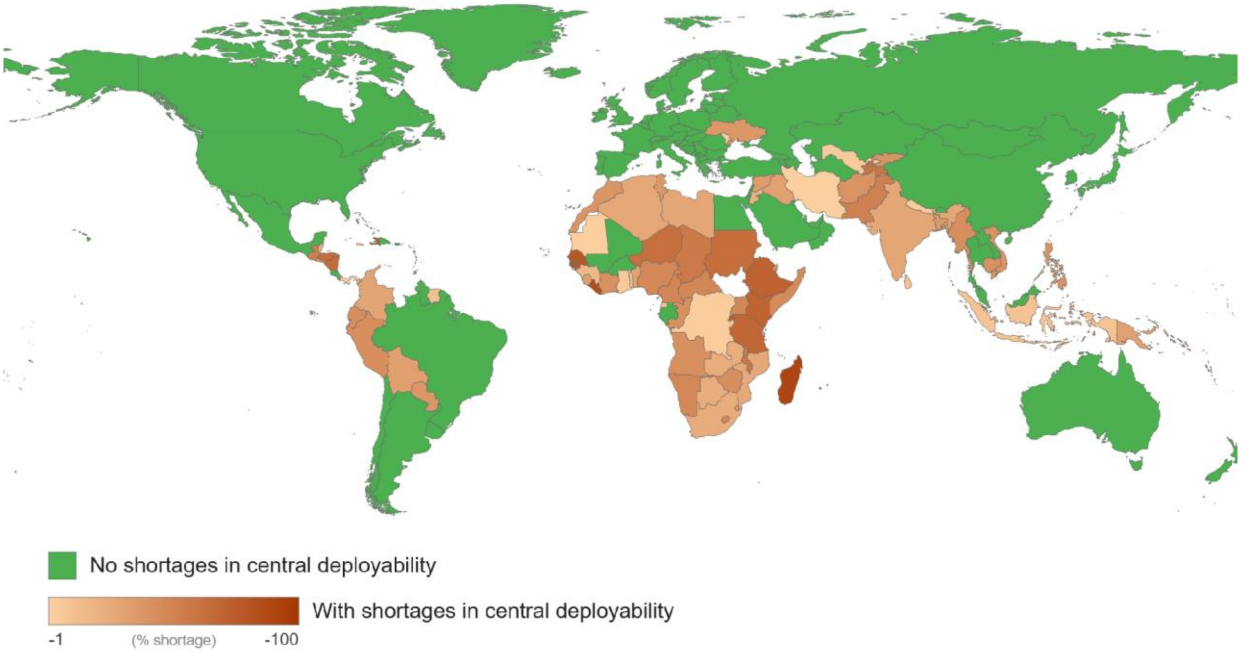
a) Comparison with VW group



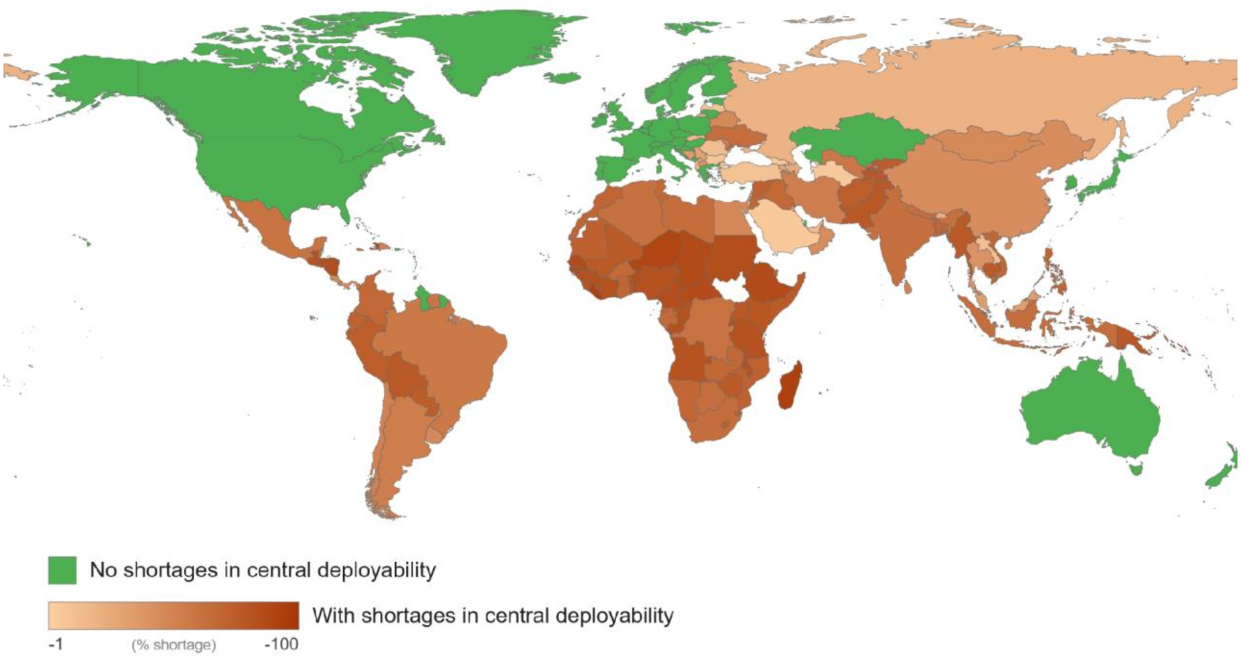
b) Comparison with EW group

Figure 8. Nation-level shortages of kitchen sinks under the central deployability scenario, with the controlled sharing protocol applied.

The national distribution of sanitary-ware shortages under the central scenario is presented in Figure 9. Relative to the VW group (Figure 9a), sanitary provision is sufficient in 10 of the 12 selected economies, with only India (−28%) and Iran (−2%) in deficit. Against the EW group (Figure 9b), however, the category exhibits widespread shortfalls, with India (−63%), Brazil (−57%), Iran (−53%), China (−44%), and Russia (−20%) all recording substantial deficits, while the United States, Germany, the United Kingdom, Australia, Singapore, and Japan maintain positive coverage. Because the aggregated sanitary-ware estimate is governed by the more limited of the toilet and shower stocks, this category represents a significant constraint on full essential-worker accommodation in the most populous countries, and the national maps confirm that adequacy is largely restricted to higher-income economies.



a) Comparison with VW group



b) Comparison with EW group

Figure 9. Nation-level shortages of sanitary ware under the central deployability scenario, with the controlled sharing protocol applied.

At the global level, the deployability adjustment materially changes the interpretation of coverage, particularly for temporary housing, refrigerators, and kitchen sinks. Under the central scenario, which is adopted here as the principal planning basis, the global stock satisfies vital-worker (VW) demand across all amenity categories, with surpluses of 10% for heating systems, 13% for cooling systems, 19% for refrigerators, 5% for cooking stoves, 22% for kitchen sinks, and 21% for sanitary ware, while temporary housing remains marginally short at −8%. For the broader essential-worker (EW) group, by contrast, every category remains in deficit under the central scenario, with shortfalls of −58% for temporary housing, −50% for heating, −48% for cooling, −45% for refrigerators, −52% for cooking stoves, −44% for kitchen sinks and −45% for sanitary ware, although these deficits are narrower than under less favorable mobilization assumptions. The low- and high-deployability scenarios provide bounds around the central estimate. Under the low-deployability scenario, even the VW group is not fully covered in any category, with shortfalls of between −21% (kitchen sinks) and −52% (temporary housing), and EW deficits widen to between −64% and −78%. Under the high-deployability scenario, all VW categories move into surplus, reaching up to +77% for kitchen sinks, yet EW coverage remains unattained throughout, with residual deficits ranging from −19% (kitchen sinks) to −44% (temporary housing). Across the full range of scenarios, therefore, protection of the VW group at the global level appears achievable under the central or high mobilization scenarios, whereas the principal global bottlenecks for full EW accommodation are not confined to total housing capacity but extend to food storage, cooking, and kitchen-related infrastructure. These global outcomes are summarised in Figure 10; the corresponding country-level deployability results, together with the theoretical (full-availability) maps, are provided in the Supplementary Material.

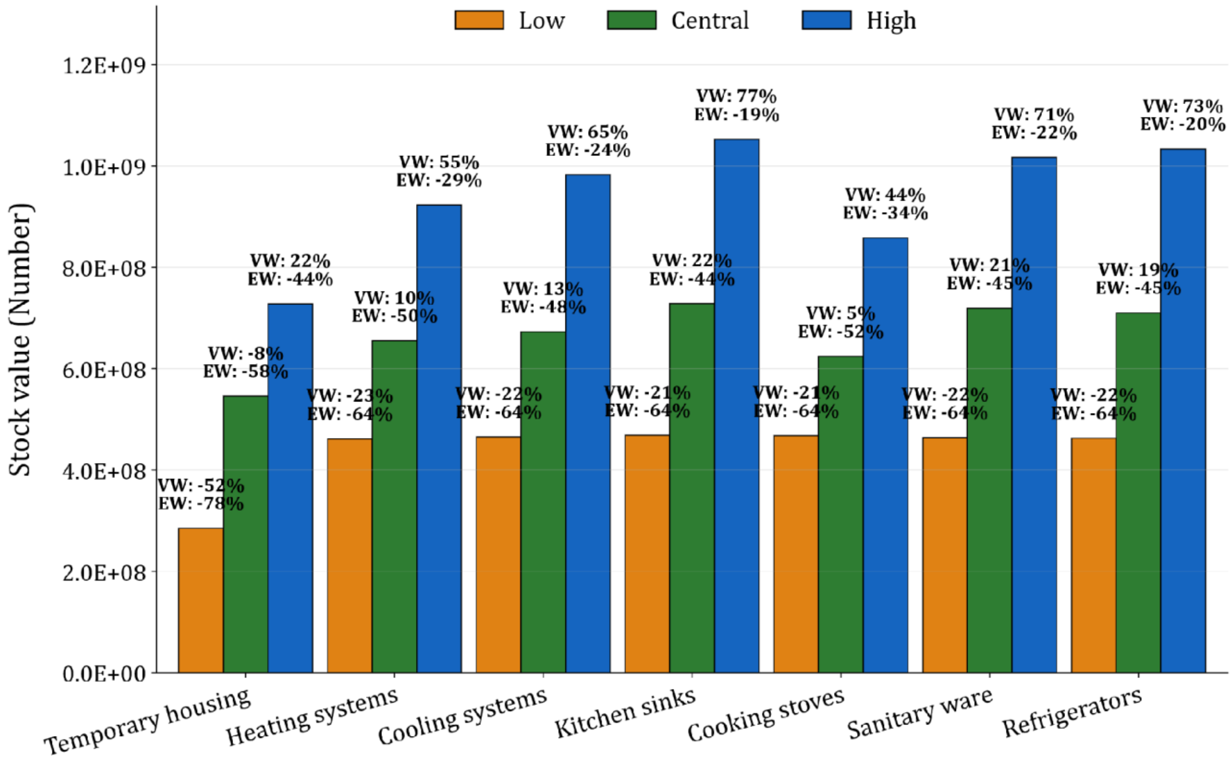


Figure 10. Global shortages of temporary housing and basic amenities under the low-, central-, and high-deployability scenarios, with the controlled sharing protocol applied.

Figures 11 and 12 depict the nation-level shortages for the selected countries based under the three deployability scenarios for the VW and EW groups, respectively. The results for the selected countries reveal considerable heterogeneity in temporary housing and amenity coverage. For the VW group, many selected countries maintain adequate or surplus capacity in housing under most deployability assumptions, although shortfalls in heating and cooling systems remain in several cases. In contrast, when assessed relative to the much larger essential worker population, the results become less favorable. While a small number of countries retain broad resilience across both housing and basic amenities, the majority face moderate to substantial shortfalls, particularly in heating, cooling, and sanitary infrastructure. Some selected countries show sufficient housing but clear deficits in supporting amenities, including the United Kingdom. A few selected countries remain severely constrained across nearly all categories, even under the high-deployability scenario. Thus, the findings indicate that while global aggregates suggest partial coverage, the selected national results show substantial disparities, and meeting the modeled needs of the essential workforce may require targeted strategies beyond increasing total stock.

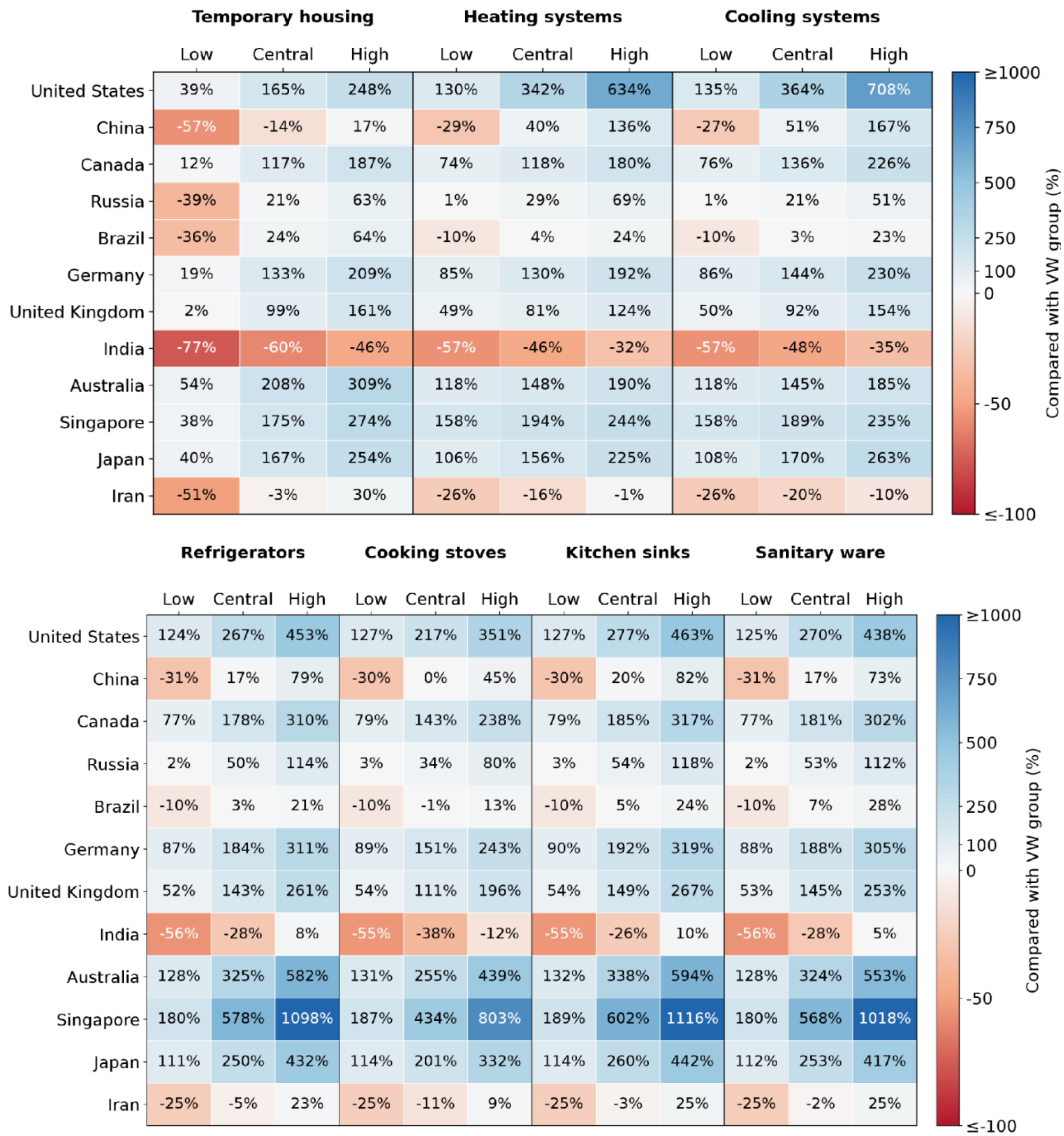


Figure 11. Nation-level shortages of temporary housing and basic amenities relative to the VW group under the low-, central-, and high-deployability scenarios, with the controlled sharing protocol applied.

Figure 12. Nation-level shortages of temporary housing and basic amenities relative to the EW group under the low-, central-, and high-deployability scenarios, with the controlled sharing protocol applied to basic amenities.

5. Conclusion

This study quantitatively assessed the capacity of existing global stocks of temporary housing and basic amenities to support the on-site isolation of essential workers during an extreme pandemic. Based on the central scenario, with full international trade and cooperation, the global community could collectively accommodate 45% of the VW population in high-quality temporary housing; the remaining VW would need to rely on lower-quality options such as converted vans and tents or would not be housed on site at all, leaving an irreducible 8% deficit even when all housing types are combined. Without international trade, only 41 of 199 countries (21%) could accommodate their entire VW population in high-quality temporary housing alone, and doing so would require a substantial logistical effort in each case; a further 61 countries (31%) could reach full VW coverage only by also drawing on lower-quality housing, while 97 countries (49%) would remain unable to fully accommodate their VW population under any combination of available stock. Under the central scenario, the global stock met VW demand for every amenity category, with surpluses of roughly 5%–22%, while temporary housing remained marginally short at −8%; relative to the broader EW group, all categories stayed in deficit, with shortfalls of between 44%–58%, corresponding to kitchen sinks and temporary housing, respectively. This gap between theoretical adequacy and realistic deployability underscores that mobilization constraints may be a major barrier to preparedness. At the national level, the disparity between the two worker groups was substantial: for the VW group most countries achieved full coverage, with deficits including several highly populous economies, including India (for example, −60% for temporary housing and −46% for heating) alongside smaller shortfalls in China and Iran; for the EW group, shortages became widespread, with populous middle-income countries such as India, Brazil, Iran, China, and Russia recording substantial deficits, while adequacy was concentrated largely among high-income economies, including the United States, Germany, Australia, Singapore, and, for several categories, the United Kingdom, Canada, and Japan. Substantial gaps remain. Food storage infrastructure requires dedicated stockpiling, kitchen sink coverage requires procurement interventions, and sanitation capacity for the broader EW group may require substantial additional investment or provisioning. Full EW accommodation under the modeled scenarios is unlikely to be achievable without prearranged access agreements, emergency access to privately held assets, rapid conversion of existing facilities, and country-specific planning targeting the most constrained infrastructure categories.

6. Limitations and future directions

Several limitations should be acknowledged when interpreting the results. First, the analysis rests on global and national stock estimates derived from 2024 market data and disaggregated to the country level partly using gross domestic product as a proxy for the distribution of housing and amenity stocks. This approach does not capture intra-national heterogeneity or country-specific differences in ownership, climate, and building practices, and it may overstate availability in economies where reported economic output is concentrated in sectors that do not closely correspond to the relevant stocks. Second, the country-level assessment is static and assumes no cross-border trade or redistribution of resources during a pandemic; while this provides a conservative, self-sufficiency-based scenario, it does not reflect the partial trade or coordinated mobilisation that might occur in practice. Third, the worker populations requiring accommodation were based on external estimates, and the exclusion of subsistence and market-oriented farmers, together with the single-occupancy allocation rule, introduces uncertainty into the demand side of the analysis.

Further limitations relate to the deployability framework and the amenity calculations. The deployability factors, although bounded by low-, central-, and high-deployability scenarios, are parameter-based estimates of the fraction of each stock that could realistically be mobilised within a one-month window, rather than empirically observed mobilization rates, and the central scenario should therefore be regarded as a structured planning scenario rather than a precise forecast. The inventory rates used to represent the share of new but uninstalled amenity units were derived from manufacturing statistics for a limited set of manufacturing sectors and were applied uniformly across countries, which do not account for national variation in production and stockholding. The amenity stocks were also assessed independently of one another, so that the co-location of complementary amenities within the same shelter was not explicitly modelled, and the aggregation of toilets and showers into a single sanitary-ware category, governed by the lower estimated stock of the two, simplifies the underlying provision. Finally, the analysis quantifies the physical availability of housing and amenities but does not address the operational, regulatory, and logistical barriers to rapid conversion or the energy, water, and waste-management requirements of sustained on-site isolation, all of which would influence real-world feasibility.

Future work could extend this inventory methodology to incorporate dynamic trade-flow modeling under pandemic-induced border restrictions. Additional research might also investigate the integration of renewable microgrids and on-site water-purification systems to further reduce logistical dependencies. Furthermore, future economic growth projections could be used to estimate when the remaining countries may be able to meet the needs of their EW and VW populations, if an extreme pandemic were to occur.

7. Conflict of interests

The authors declare no conflict of interest.

8. Acknowledgements

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The authors used generative AI tools only for language editing; all content was reviewed and approved by the authors, who take full responsibility for it.

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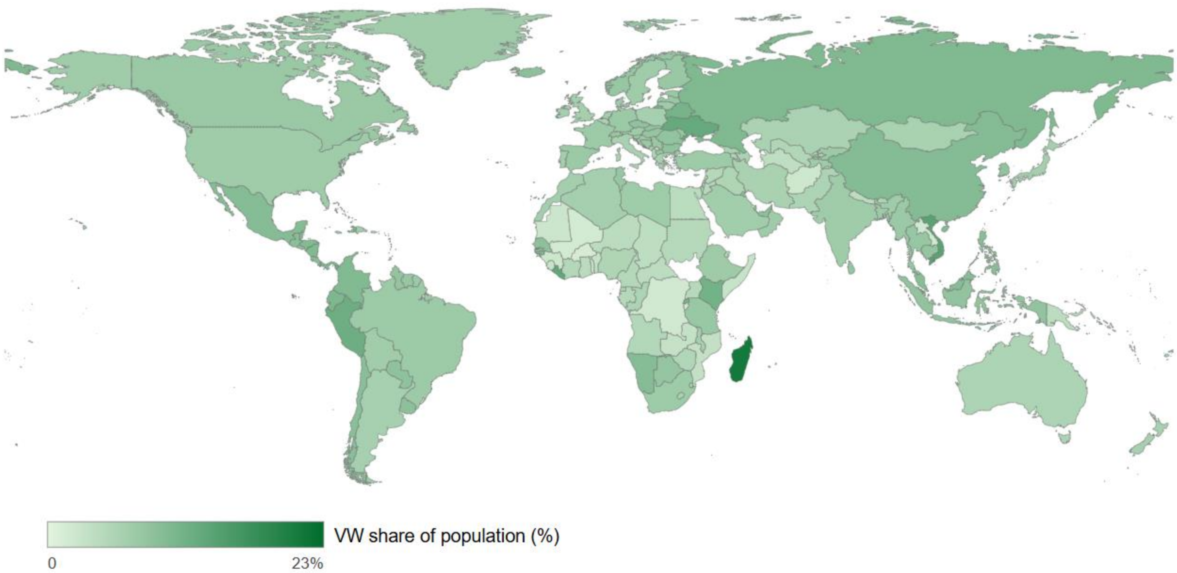
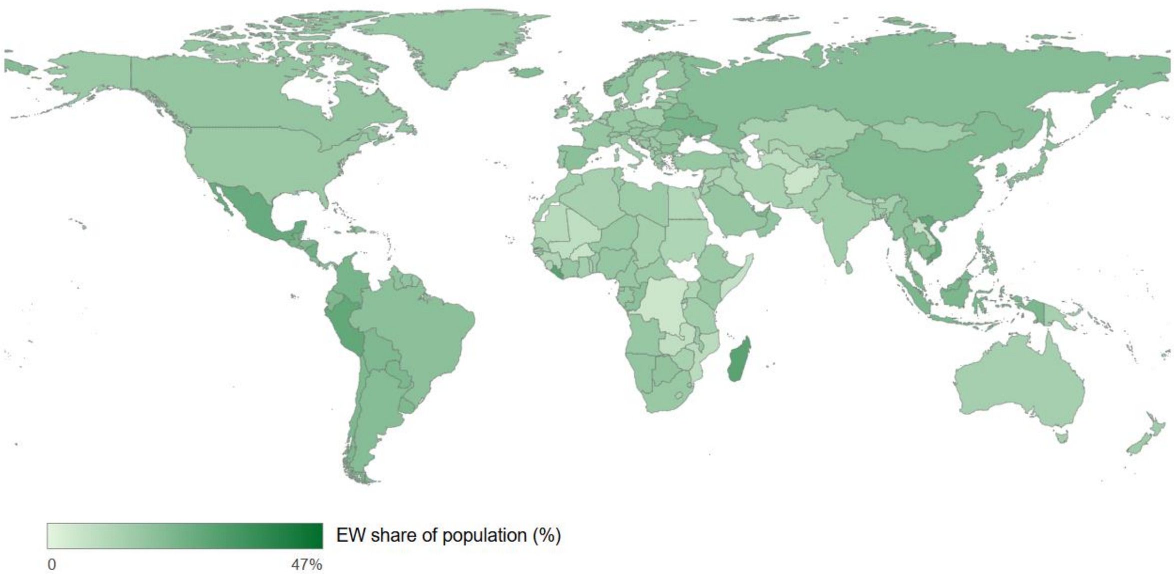
9. Appendix

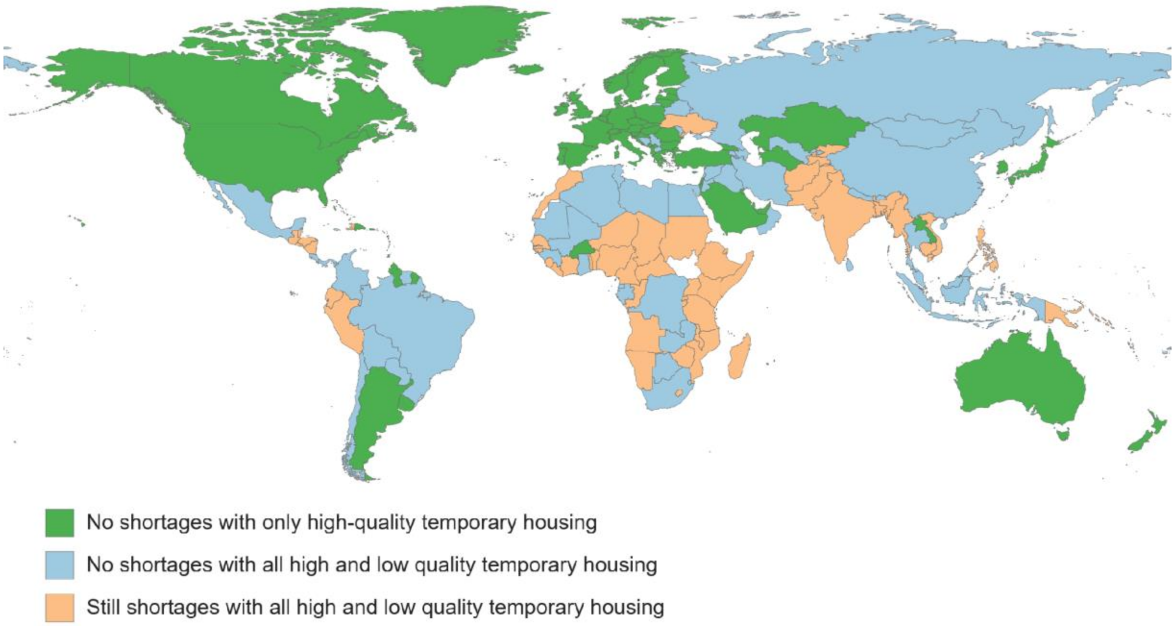


a) VW share of population

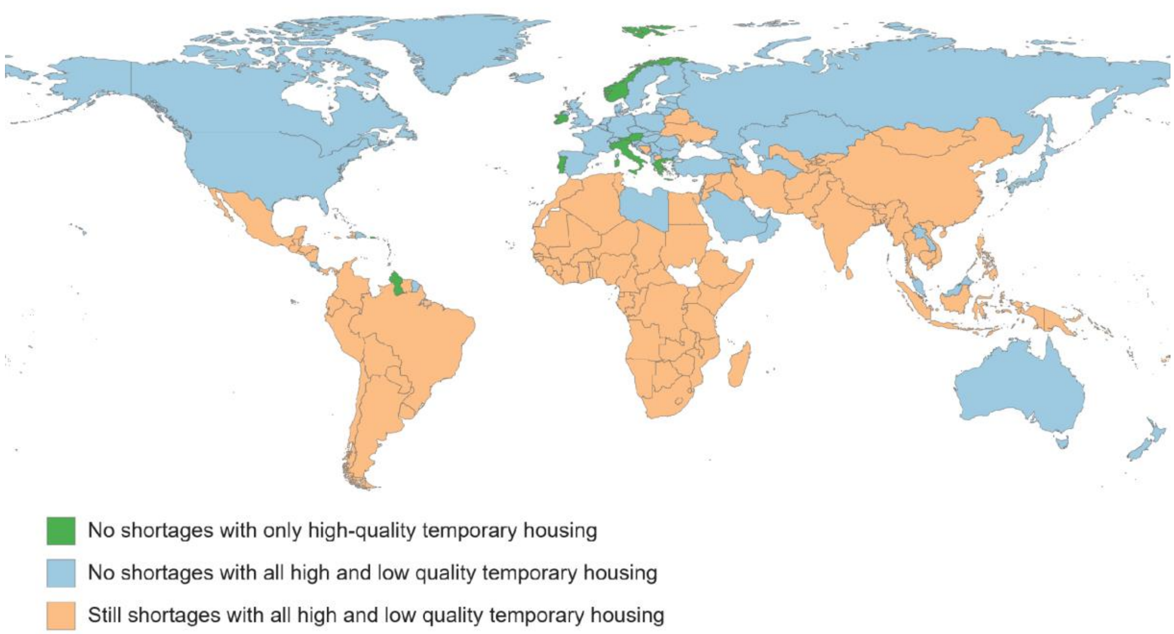


b) EW share of population

Figure A. Share of vital/essential workers worldwide.



a) Comparison with VW group



b) Comparison with EW group

Figure B. Shortages of temporary housing worldwide assuming theoretical availability.

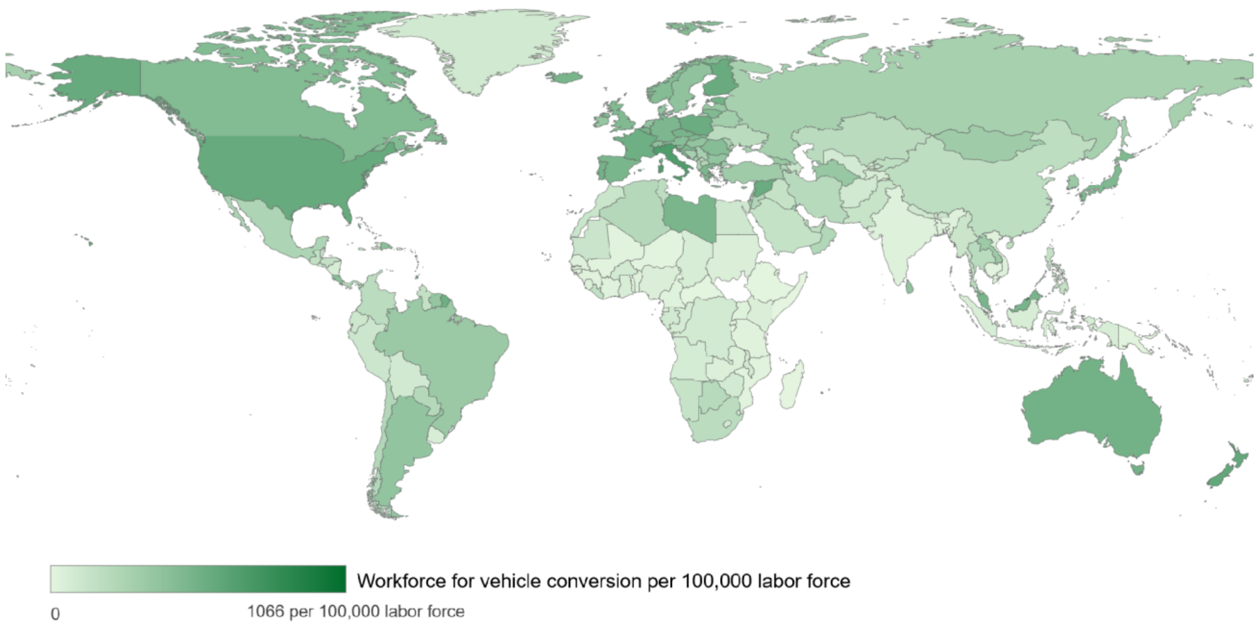


Figure C. Required vehicle-conversion workers per 100,000 labor force.

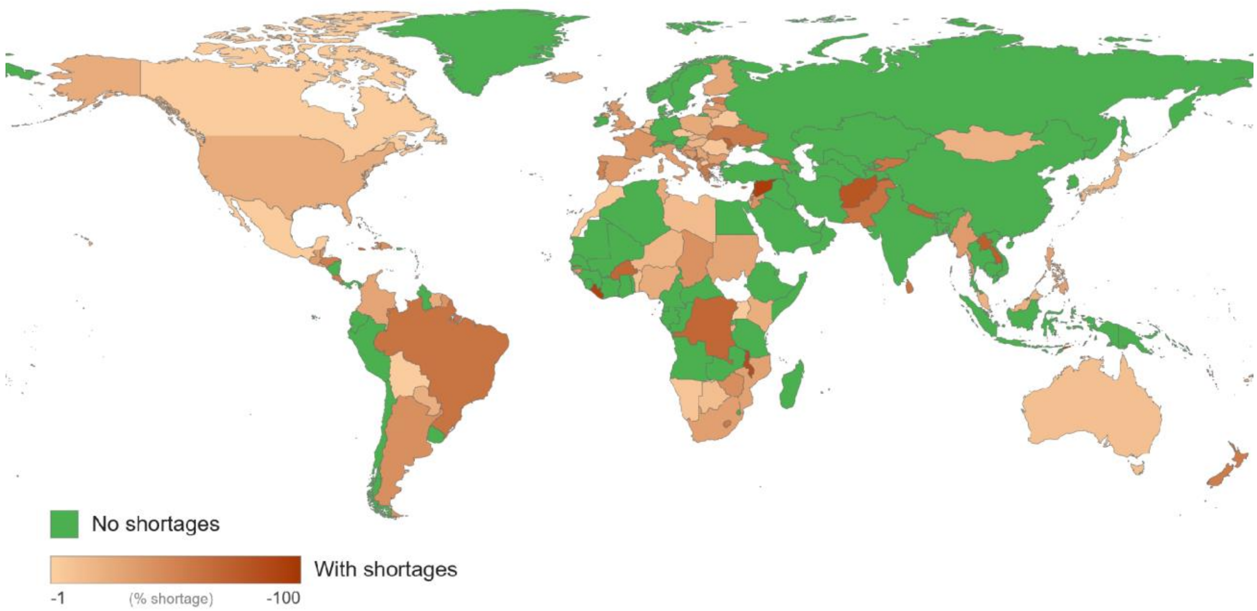
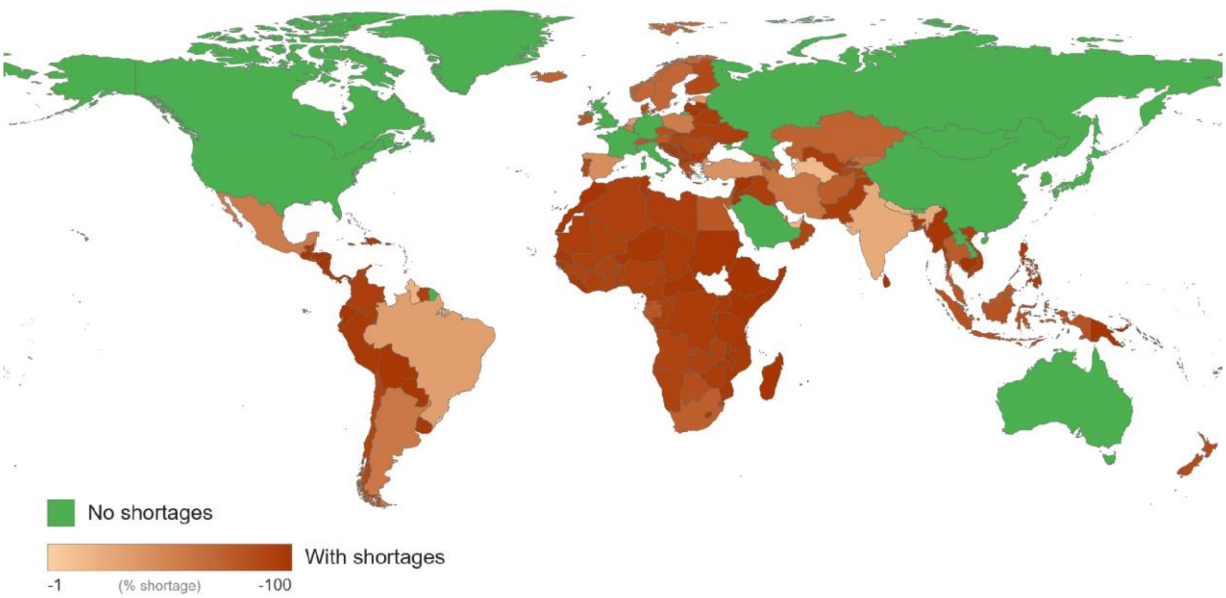
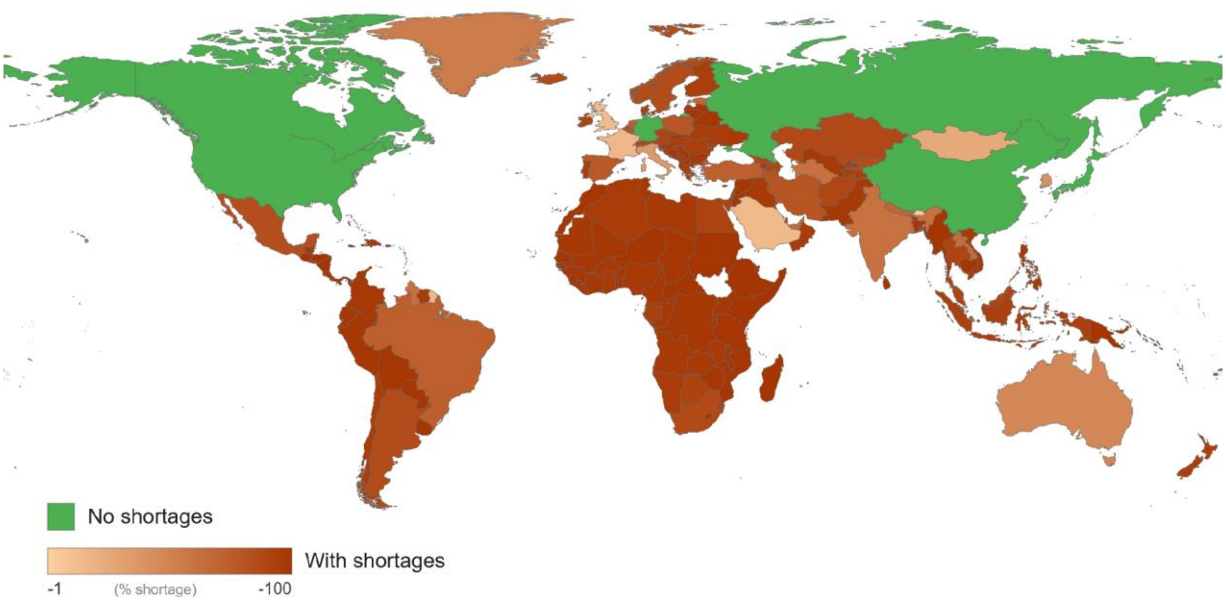


Figure D. Shortages of thermal insulation worldwide.

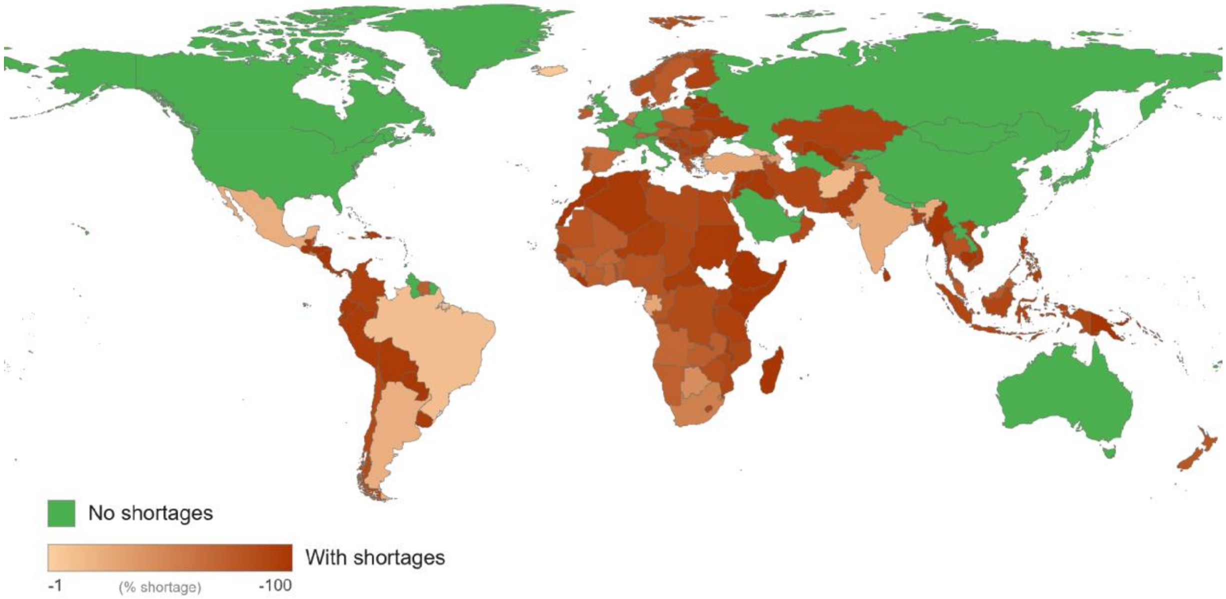


a) Comparison with VW group

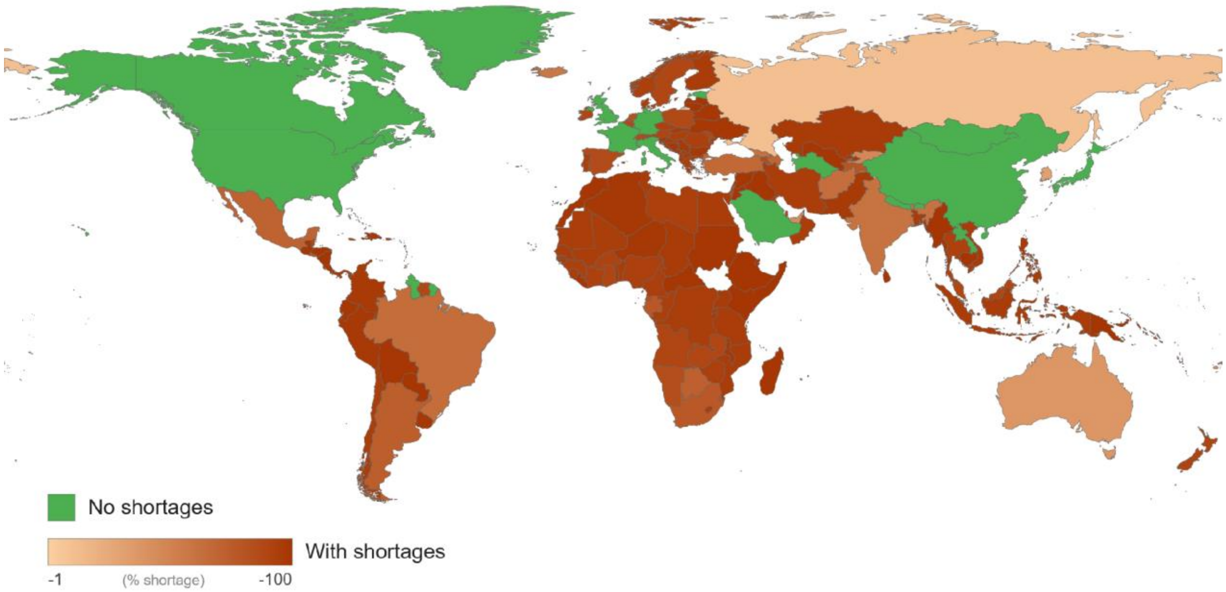


b) Comparison with EW group

Figure E. Shortages of all types of space heating systems worldwide.

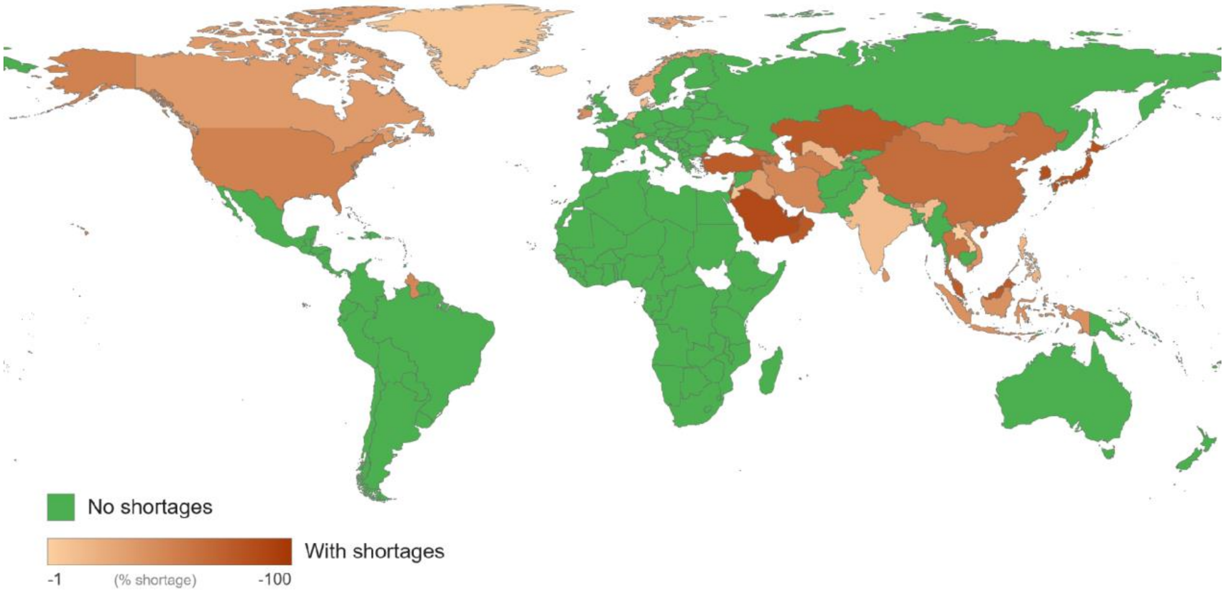


a) Comparison with VW group

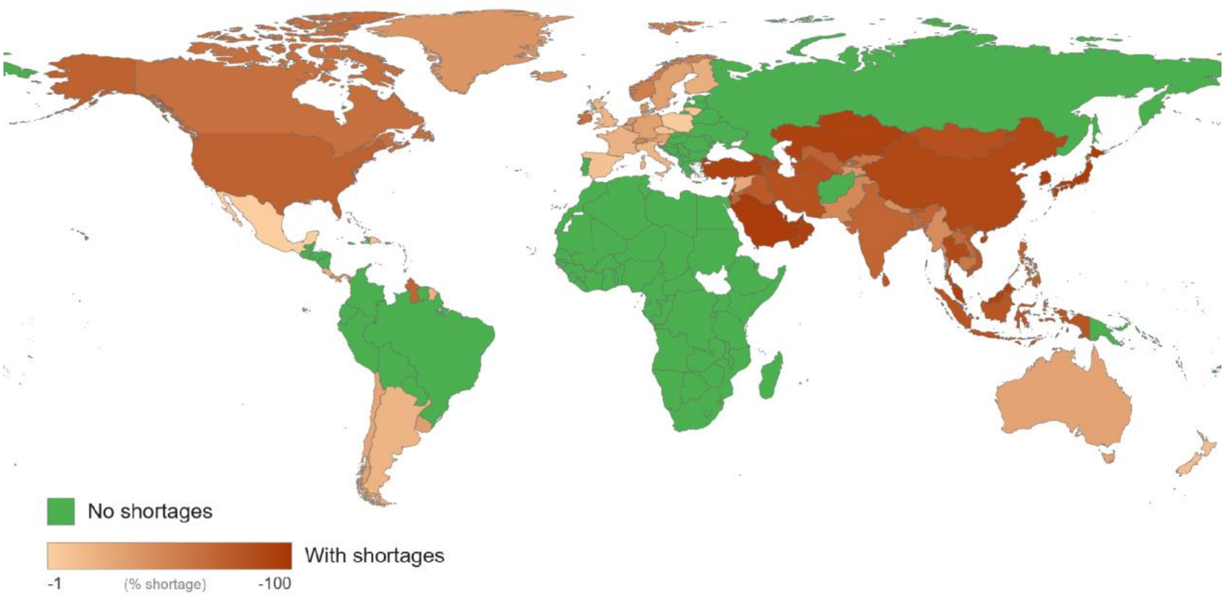


b) Comparison with EW group

Figure F. Shortages of all types of space cooling systems worldwide.



a) Electrician shortages



b) Plumber shortages

Figure G. Shortages of housing-related labour force worldwide.

Table A. Input parameters and resulting global stock estimates by housing and amenity sub-type.

Category / sub-type	Annual Global Market Size (USD)	Market revenue share (%)	Compound annual growth rate (%)	Average unit price (USD)	Average lifespan (years)
Temporary housing					
Mobile homes	Annual Global Market Size (USD)	Market revenue share (%)	Compound annual growth rate (%)	Average unit price (USD)	Average lifespan (years)
	24,270,000,000	100	6.0	100,000	55
	Link			Link	Link
Customised container housing	Annual Global Market Size (USD)	Market revenue share (%)	Compound annual growth rate (%)	Average unit price (USD)	Average lifespan (years)
	65,000,000,000	100	6.0	75,000	30
	Link			Link	Link
Near-site company workforce housing	Annual Global Market Size (USD)	Market revenue share (%)	Compound annual growth rate (%)	Average unit price (USD)	Average lifespan (years)
	18,700,000,000	100	6.0	30,000	25
	Link			Link	Link
Recreational caravans	Annual Global Market Size (USD)	Market revenue share (%)	Compound annual growth rate (%)	Average unit price (USD)	Average lifespan (years)
	56,350,000,000	100	6.0	75,000	20
	Link			Link	Link
Micro living pods	Annual Global Market Size (USD)	Market revenue share (%)	Compound annual growth rate (%)	Average unit price (USD)	Average lifespan (years)
	250,000,000	100	6.0	30,000	15
	Link			Link	Link
Prefabricated foldable units	Annual Global Market Size (USD)	Market revenue share (%)	Compound annual growth rate (%)	Average unit price (USD)	Average lifespan (years)
	8,550,000,000	100	6.0	15,000	25
	Link			Link	Link
Panelised modular buildings	Annual Global Market Size (USD)	Market revenue share (%)	Compound annual growth rate (%)	Average unit price (USD)	Average lifespan (years)
	120,660,000,000	100	6.0	150,000	30
	Link			Link	Link
Emergency shelters	Annual Global Market Size (USD)	Market revenue share (%)	Compound annual growth rate (%)	Average unit price (USD)	Average lifespan (years)
	997,600,000	100	6.0	150,000	20
	Link			Link	Link
Standard shipping containers	Annual Global Market Size (USD)	Market revenue share (%)	Compound annual growth rate (%)	Average unit price (USD)	Average lifespan (years)
	10,600,000,000	100	6.0	3,500	15
	Link			Link	Link
Tents	Annual Global Market Size (USD)	Market revenue share (%)	Compound annual growth rate (%)	Average unit price (USD)	Average lifespan (years)
	4,000,000,000	100	6.0	150	10
	Link			Link	Link
Solar power reefer containers	Annual Global Market Size (USD)	Market revenue share (%)	Compound annual growth rate (%)	Average unit price (USD)	Average lifespan (years)
	289,000,000	100	17.0	10,000	15
	Link			Link	Link
Dockside bed ships / houseboats	Annual Global Market Size (USD)	Market revenue share (%)	Compound annual growth rate (%)	Average unit price (USD)	Average lifespan (years)
	907,100,000	100	5.0	75,000	30
	Link			Link	Link
Heating systems					
Electrical space heater	Annual Global Market Size (USD)	Market revenue share (%)	Compound annual growth rate (%)	Average unit price (USD)	Average lifespan (years)
	8,200,000,000	61.40	6.90	100	15
	Link			Link	Link
Gas space heater	Annual Global Market Size (USD)	Market revenue share (%)	Compound annual growth rate (%)	Average unit price (USD)	Average lifespan (years)

Category / sub-type	Annual Global Market Size (USD)	Market revenue share (%)	Compound annual growth rate (%)	Average unit price (USD)	Average lifespan (years)
	8,200,000,000	38.60	6.90	100	15
	Link			Link	Link
Master Air-Bus BV	Annual Global Market Size (USD)	Market revenue share (%)	Compound annual growth rate (%)	Average unit price (USD)	Average lifespan (years)
	1,300,000,000	100	6.00	5,000	20
	Link			Link	Link
Furnace (all types)	Annual Global Market Size (USD)	Market revenue share (%)	Compound annual growth rate (%)	Average unit price (USD)	Average lifespan (years)
	8,911,200,000	40.00	3.40	7,000	20
	Link			Link	Link
Infrared heat lamps	Annual Global Market Size (USD)	Market revenue share (%)	Compound annual growth rate (%)	Average unit price (USD)	Average lifespan (years)
	1,200,000,000	100	6.40	275	3
	Link			Link	Link
Heat pump *	Annual Global Market Size (USD)	Market revenue share (%)	Compound annual growth rate (%)	Average unit price (USD)	Average lifespan (years)
	149,510,000,000	60.00	6.80	1,000	10
	Link			Link	Link
Cooling systems					
Air conditioner	Annual Global Market Size (USD)	Market revenue share (%)	Compound annual growth rate (%)	Average unit price (USD)	Average lifespan (years)
	149,510,000,000	40.00	6.80	1,000	10
	Link			Link	Link
Cooling fans (all types)	Annual Global Market Size (USD)	Market revenue share (%)	Compound annual growth rate (%)	Average unit price (USD)	Average lifespan (years)
	33,000,000,000	100	2.50	250	10
	Link			Link	Link
Heat pump *	Annual Global Market Size (USD)	Market revenue share (%)	Compound annual growth rate (%)	Average unit price (USD)	Average lifespan (years)
	149,510,000,000	60.00	6.80	1,000	10
	Link			Link	Link
Refrigerators					
Household refrigerator	Annual Global Market Size (USD)	Market revenue share (%)	Compound annual growth rate (%)	Average unit price (USD)	Average lifespan (years)
	78,390,000,000	100	6.86	978	20
	Link			Link	Link
Mini fridge	Annual Global Market Size (USD)	Market revenue share (%)	Compound annual growth rate (%)	Average unit price (USD)	Average lifespan (years)
	1,600,000,000	100	8.30	158	10
	Link			Link	Link
Cooking stoves					
Portable cooking stove	Annual Global Market Size (USD)	Market revenue share (%)	Compound annual growth rate (%)	Average unit price (USD)	Average lifespan (years)
	11,643,740,000	100	8.82	400	10
	Link			Link	Link
Kitchen sinks					
Portable kitchen sink	Annual Global Market Size (USD)	Market revenue share (%)	Compound annual growth rate (%)	Average unit price (USD)	Average lifespan (years)
	120,000,000	100	9.20	600	20
	Link			Link	Link
Portable hand wash station	Annual Global Market Size (USD)	Market revenue share (%)	Compound annual growth rate (%)	Average unit price (USD)	Average lifespan (years)
	1,119,130,000	100	4.45	1,000	15
	Link			Link	Link
Dishwashers	Annual Global Market Size (USD)	Market revenue share (%)	Compound annual growth rate (%)	Average unit price (USD)	Average lifespan (years)
	8,900,000,000	100	7.40	800	12
	Link			Link	Link
Sanitary ware §					

Category / sub-type	Annual Global Market Size (USD)	Market revenue share (%)	Compound annual growth rate (%)	Average unit price (USD)	Average lifespan (years)
Portable shower	Annual Global Market Size (USD)	Market revenue share (%)	Compound annual growth rate (%)	Average unit price (USD)	Average lifespan (years)
	2,241,000,000	100	5.71	1,000	2
	Link			Link	Link
Portable toilet	Annual Global Market Size (USD)	Market revenue share (%)	Compound annual growth rate (%)	Average unit price (USD)	Average lifespan (years)
	18,030,000,000	100	6.80	1,000	10
	Link			Link	Link

* Heat pumps are reported under both heating and cooling systems, as they provide both functions; the corresponding stock is included in each category total.

§ The aggregated sanitary-ware stock is governed by the more limited of the portable-shower and portable-toilet inventories, since both are required for complete sanitation provision.