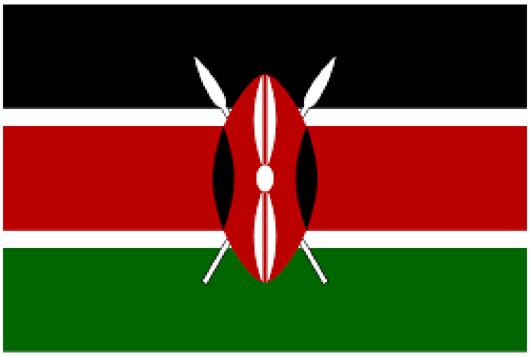
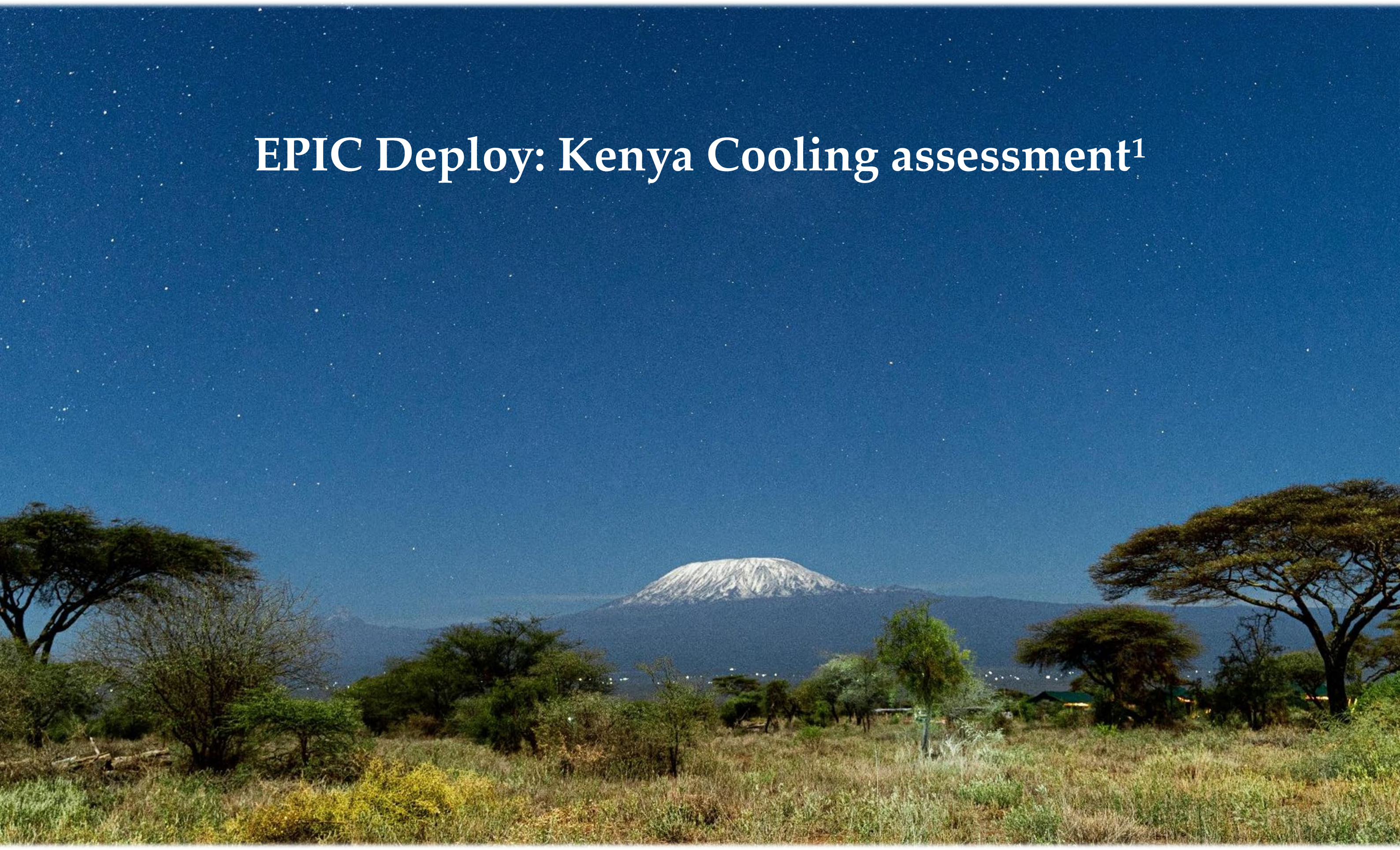
# Kenya



## EPIC Deploy: Kenya Cooling assessment[1]



POLITECNICO MILANO 1863

Ministero dell'Ambiente e della Sicurezza Energetica

UN environment programme

[1] **Scope and use:** This report provides contextual and screening-level information to support the preparation of applications. It is not a technical design standard, legal opinion, official national inventory or substitute for site-specific due diligence. Applicants remain responsible for validating demand, baseline conditions, equipment sizing, regulatory compliance and expected emission reductions for the proposed project.

# Cooling Demand Taxonomy

Kenya's cooling landscape is shaped by rapid demographic growth, pronounced climatic heterogeneity, constrained energy infrastructure, and an evolving regulatory framework. The key country framework conditions are summarised in Table 1 as a quick reference. The sections that follow develop each dimension in greater detail.

*Table 1 – Kenya: key cooling taxonomy data*

| **Economics and Demographics** | | **Climatic conditions** | |
|---|---|---|---|
| GDP (2024) | approx. USD 120 B [1] | National avg. Cooling Degree Days (18°C base) | 2,813 °C·day/yr [2] |
| GDP per capita | approx. USD 2,130 [3] | Mean annual temperature range | 18.3–30.3 °C average nighttime-to-daytime range; local highs can reach 40 °C [4] |
| GDP growth rate (medium-term) | approx. 5%/yr [5] | Coastal relative humidity | approx. 80% [4] |
| Total population (2024) | approx. 56.4 M [6] | Hot days projected by mid-century | up to 45% of days/yr [4] |
| Population growth rate | 2.0%/yr [7] | Warming trend since 1960 | +1.0 °C (0.21 °C/decade) [8] |
| Urban population share | approx. 30% [9] | Projected warming by 2050s (BAU) | +1.7 °C [4] |
| Urban growth rate | 2.8%/yr [10] | | |
| Share of urban pop. in informal settlements | >51% [4] | | |
| Growth-driving sectors | Agrifood, services, tourism [11][12] | | |
| **Energy infrastructure** | | **Regulatory framework** | |
| National electrification rate | 76.2% [13] | MEPS for cooling appliances | In force (KS 2463:2019; KS 2464-2:2020) [14][15] |
| Urban electricity access | approx. 90% [13] | R22 phase-out target | 2026 [16] |
| Rural electricity access | approx. 68% [13] | HFC phase-down (Kigali Amendment) | Ongoing, accelerated schedule [17] |
| Renewable share of generation | approx. 91% in the generation mix shown in Figure 4 [18] | National Cooling Action Plan | NCAP 2023 [16] |
| Grid reliability | Low (avg. 3.5 outages/month) [18] | NDC emissions reduction target | 32% by 2030 [8] |
| Residential electricity tariff | USD 0.16–0.25/kWh [18] | Import conformity requirement | KEBS PVoC/CoC before shipment [19] |
| Total electricity production | 12.84 TWh/yr [18] | Energy efficiency regulation | EPRA model registration mandatory [14] |
| Grid CO2 emission factor (electricity-consumption screening factor) | 0.274 $kgCO_2$/kWh [20][21] | | |

# General Overview

## Geography and climate

Kenya's three climatic zones differ substantially in temperature, humidity, and population density, and generate correspondingly different cooling needs. The ASAL region covers almost 90% of the national territory and faces the highest ambient temperatures, yet remains predominantly off-grid and underserved by formal infrastructure. The temperate highlands concentrate the bulk of urban economic activity and cooling market potential. The humid coastal zone presents a distinct challenge, as moderate temperatures combined with persistently high relative humidity make thermal comfort harder to achieve than temperature data alone would suggest. The zonal breakdown in Figure 1 along with the data in Table 2 reflects this complexity and serves as a reference framework throughout the assessment.

*Table 2 – Kenya: climatic zone general data*

| **Arid & Semi-Arid Lands** (ASALs) | | |
|---|---|---|
| Area share | Mean temperature | Key cooling relevance |
| 88.9% [22] | High 30s; local highs can reach 40 °C (Turkana) [4] | Highest cooling demand<br>37.9% of population<br>Off-grid<br>Pastoralist [22] |
| **Temperate highlands** (incl. Nairobi) | | |
| Area share | Mean temperature | Key cooling relevance |
| 8.9% [22] | Cooler conditions moderated by elevation [23] | 55.6% of population<br>Urban infrastructure hub [22] |
| **Humid coastal zone** (incl. Mombasa) | | |
| Area share | Mean temperature | Key cooling relevance |
| 2.2% [22] | Daily maxima around 31 °C RH around 80% [4] | High density<br>6.5% of population<br>Humidity-driven<br>Sea-level risk [22] |

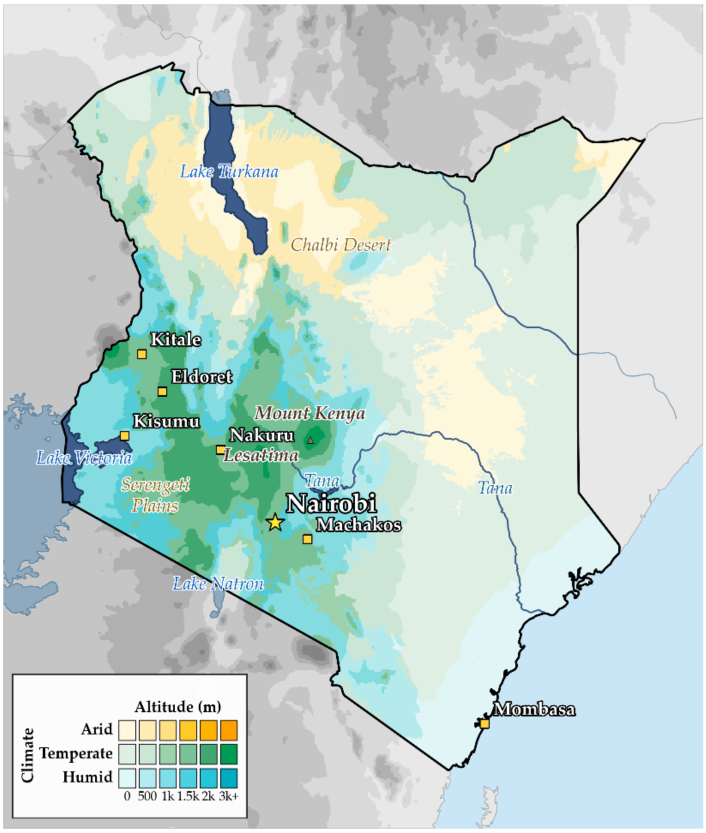



*Figure 1 – Kenya: geography and climatic zones*

Climate projections compound the structural cooling challenge across all three zones. Kenya is experiencing sustained warming: mean annual temperatures have risen approximately 1.0 °C since 1960 (0.21 °C/decade) [8]. Under business-as-usual scenarios, further increases of 1.7 °C are projected by the 2050s and up to 3.5 °C by end of century [4]. As represented in Figure 2, the national average stands at 2,813 Cooling Degree Days [2] and hot days are projected on up to 45% of days per year by mid-century [23]. Without efficiency improvements, RAC sector GHG emissions are projected to roughly double by 2050, approximately 8 Mt $CO_2$eq [24]. Currently, 9.6 million Kenyans are at high risk from lack of cooling access, of whom 5.1 million are rural poor [4].

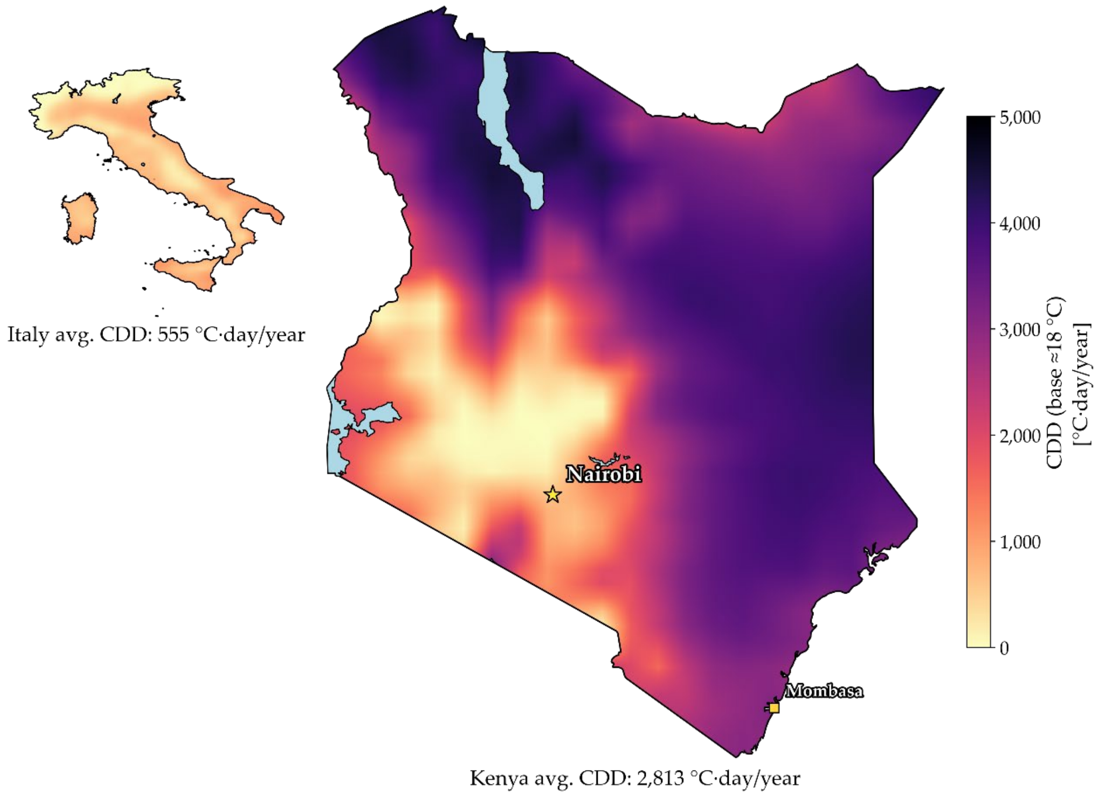



*Figure 2 – Kenya: cooling degree days 18°C spatial distribution*

## Population, Urbanisation and Vulnerability

Kenya's population is growing rapidly, with urbanisation accelerating beyond the capacity of formal infrastructure to absorb it. Key demographic and vulnerability indicators are reported in Table 3.

*Table 3 – Kenya: general demographic data*

| Indicator | Value |
|---|---|
| Total Population (2024) | 56.4 M [6] |
| Population growth rate | 2.0%/yr [7] |
| Urban population share | approx. 30% (2024) [9] |
| Urban growth rate | 2.8%/yr [10] |
| Projected urban share by 2050 | approx. 50% [25] |
| Projected population by 2030 | approx. 62 M [6][7] |
| Share of urban population in informal settlements | >51% [4] |
| ASAL population | approx. 20 M [22] |
| Mombasa County density | approx. 5,500 p/km² [26] |

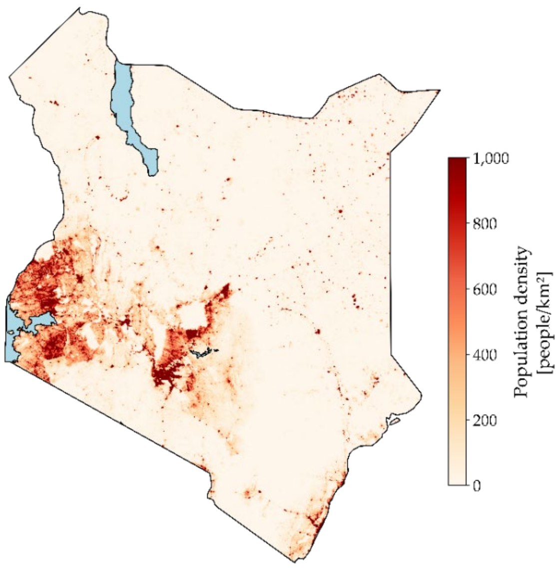



*Figure 3 – Kenya: population density [25]*

Urbanisation is partly climate-driven, with drought and flood-induced displacement from rural areas accelerating the growth of informal settlements. More than 51% of Kenya's urban population lives in such settlements, which are thermally highly vulnerable: mabati (corrugated iron) roofing generates severe indoor overheating, while minimal vegetation and poor ventilation amplify heat stress [26]. Limited electricity access in these areas further constrains adaptive capacity.

## Building Stock and Thermal Exposure

The built environment is a primary determinant of heat risk in Kenya's urban centres. Lightweight corrugated-metal construction is widespread in informal settlements and contributes to elevated indoor heat exposure [27][28]. Urban heat island effects add 2–8 °C in Nairobi and Mombasa, with peak differentials in dense informal areas reaching up to 15 °C relative to rural surroundings [29]. This concentrates thermal risk disproportionately on low-income populations and is directly associated with increased hospital admissions during periods of extreme heat [30].

## Economy and Energy Poverty

Affordability is a structural constraint on cooling access across Kenya. Selected economic indicators relevant to cooling market potential and financing are reported in Table 4.

*Table 4 – Kenya: main economic indicators*

| Indicator | Value | Source |
|---|---|---|
| GDP (2024) | approx. USD 120 B | [1] |
| GDP per capita | approx. USD 2,130 | [3] |
| Medium-term growth rate | approx. 5%/yr | [5] |
| Climate-related economic cost | 3–5% of GDP/yr | [8] |
| Rural population without formal electricity access | approx. 32% (67.9% rural access, 2023) | [13] |
| Agriculture share of GDP | up to 33% | [11] |
| Rural workforce in agriculture | >70% | [11] |
| Post-harvest food losses | High and commodity-dependent; the current national policy estimate is discussed in the food cold-chain section | [4][12] |
| Cold-chain market structure | Fragmented outside high-value export chains | [12] |

With a GDP per capita of approximately USD 2,130 and around one third of the rural population lacking formal electricity access, the market for modern cooling solutions remains constrained outside urban centres because formal access does not always imply reliable, affordable electricity for cooling loads. At the same time, substantial and commodity-dependent post-harvest losses, together with the fragmented structure of domestic cold chains, indicate a significant need for improved storage and temperature management in agricultural value chains [4][12].

## Electricity system

As represented in Figure 4, Kenya's electricity system is characterised by a high renewable share and a rapidly expanding grid, alongside significant reliability constraints that directly affect cooling system design and financing. Key system indicators are reported in Table 5.

With grid outages averaging 3.5 per month and residential tariffs ranging from USD 0.16 to 0.25/kWh, off-grid and hybrid solutions remain relevant alongside grid-connected options. Hydropower dependency creates systemic seasonal vulnerability, as peak cooling demand coincides with lowest hydro output during dry periods. Without efficiency improvements, residential cooling is projected to account for 7 to 13% of total national electricity consumption by 2030 [16].

*Table 5 – Kenya: electricity system key indicators*

| Indicator | Value | Source |
|---|---|---|
| National electrification rate | 76.2% | [13] |
| Urban access (large cities) | approx. 90% | [13] |
| Rural access (small centres) | approx. 68% | [13] |
| Renewable share of generation | approx. 91% | [18] |
| Geothermal | approx. 43% (generation share) | [31] |
| Hydropower | approx. 28% | [31] |
| Total production | 12.84 TWh/yr | [18] |
| Consumption growth (2000–2023) | +73% | [18] |
| Grid outages (avg.) | approx. 3.5/month, approx. 2.3 h/event | [18] |
| Residential electricity tariff | \$0.16–0.25/kWh | [18] |
| Grid CO2 emission factor (electricity-consumption screening factor) | 0.274 $kgCO_2/kWh$ | [20][21] |

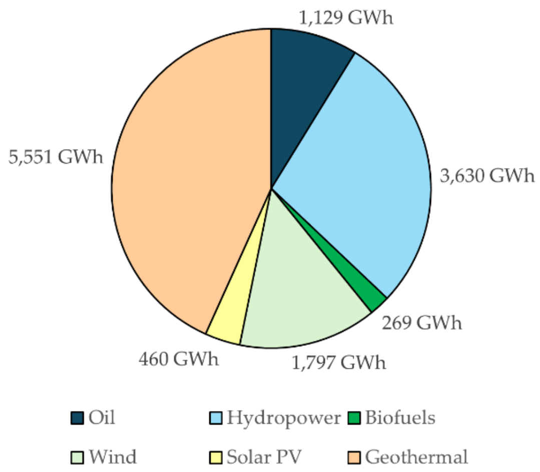



*Figure 4 – Kenya: electricity production share [18]*

For the screening calculations in this report, indirect emissions from grid electricity consumption use 0.274 $tCO_2/MWh$. This is the Kenya electricity-consumption factor in the Harmonized IFI Default Grid Factors 2021, version 3.2, selected in accordance with the IFI Tier 1 approach for projects using grid electricity [20][21]. It is a harmonized default factor rather than a current utility-specific or project-specific value. Applicants should apply the emission factor and monitoring methodology required by the call and verify whether a more recent approved factor is available when preparing project-level emission estimates.

# Regulatory Framework

## Key legislation

Kenya has developed a progressively structured regulatory framework for cooling, combining energy efficiency obligations, refrigerant phase-out commitments, and market entry requirements. The key legislative instruments are summarised in Table 6. Enforcement is distributed across multiple authorities, each with a distinct mandate covering standards, refrigerant controls, import certification, and public procurement.

*Table 6 – Kenya: list of administrative key provisions*

| Instrument | Year | Key provision |
|---|---|---|
| Energy Act 2006 | 2006 | Foundation of energy regulation [32] |
| Energy Management Regulations 2012 | 2012 | Demand-side management obligations [33] |
| Energy (Appliances' Energy Performance and Labelling) Regulations 2016 | 2016 | MEPS and label registration for regulated appliances [14] |
| Energy Act 2019 (Act No. 1 of 2019) | 2019 | Consolidated EPRA mandate; MEPS enforcement [34] |
| National Cooling Action Plan (NCAP) 2023 | 2023 | Multi-sectoral strategy: efficient cooling, low-GWP refrigerants, cold chain access [16] |

In practice, gaps remain between the normative framework and its application, particularly for import controls and field verification of MEPS compliance.

## MEPS in force for cooling appliances

Minimum energy performance standards are currently in force for room air conditioners and refrigerating appliances. Both product categories require EPRA model registration before import or sale. R22 is not registrable for new equipment. Applicable standards are set out in Table 7.

*Table 7 – Kenya: MEPS in force for cooling appliances*

| Product | Standard | Key requirement |
|---|---|---|
| Room air conditioners | KS 2463:2019 | EPRA model registration before import/sale<br>R22 not registrable [15][35][14] |
| Refrigerating appliances | KS 2464-2:2020 | MEPS/energy label<br>Model registration [14] |

## Refrigerant transition timeline

Kenya has committed to an accelerated refrigerant phase-out schedule, running ahead of the Montreal Protocol baseline in several respects. R32 is the preferred transitional refrigerant for split air conditioners, while natural refrigerants are the target for chillers, cold rooms, and medical equipment. Transition milestones are set out in Table 8.

*Table 8 – Kenya: refrigerant transition targets*

| Milestone | Target |
|---|---|
| R22 phase-out (new installations) | 2026 (4 years ahead of Montreal Protocol) [16] |
| HFC phase-down under Kigali Amendment | Ongoing. Accelerated schedule [17] |
| Preferred transitional refrigerant (split ACs) | R32 (GWP 675) [16] |
| Target refrigerants (chillers, cold rooms) | R290, $NH_3/CO_2$ cascade, $CO_2$ [16] |
| Medical refrigerators | R-600a (isobutane) [16] |

## Key institutions

Regulatory oversight for cooling is shared across five principal authorities, each with a distinct mandate covering standards, refrigerant controls, import certification, and public procurement. Their respective mandates are summarised in Table 9.

*Table 9 – Kenya: cooling key authorities*

| Authority | Role for cooling |
|---|---|
| EPRA | MEPS/labelling, model registration, electrical contractor licensing, energy audits [14][34] |
| KEBS | National standards, PVoC/CoC certification, ISM [19] |
| NEMA / National Ozone Unit | Refrigerant controls, HCFC/HFC phase-out, Kigali implementation [16][17] |
| KRA / Customs | Import duties, VAT, IDF, RDL, clearance [36] |
| PPRA | Public procurement regulation; 30% AGPO reservation for eligible enterprises [37] |

Conformity assessment, model registration and refrigerant controls are distributed across EPRA, KEBS and the National Ozone Unit, making these institutions central to the market-entry framework for cooling equipment.

## Import and market-entry framework for cooling equipment

Cooling equipment entering the Kenyan market is subject to conformity certification, product registration, customs charges and refrigerant controls. The main elements of this framework are summarised below:

- KEBS PVoC / Certificate of Conformity: regulated products are generally subject to pre-export verification by a KEBS-authorised PVoC agent. Non-compliant consignments may be detained or rejected at the port of entry. CE test reports can support conformity documentation, subject to product-specific acceptance [19].
- Import Standardisation Mark (ISM): products intended for sale in Kenya may also fall within the ISM framework [19].
- EPRA model registration: room air conditioners and refrigerating appliances covered by the 2016 Regulations are subject to model registration before sale or supply. The treatment of foreign test reports depends on the applicable registration procedure [14][15].
- KRA import duties and levies: charges vary by HS classification and may include import duty, VAT, the Import Declaration Fee and the Railway Development Levy. The EU–Kenya Economic Partnership Agreement entered into force in July 2024; an interim East African Court of Justice order issued in November 2025 stayed implementation pending determination of Reference No. 10 of 2024 [36][38].
- NEMA refrigerant controls: HCFCs and other controlled substances are subject to notification and phase-out controls. R22 is not part of the policy direction for new installations [16][17].

Table 10 summarises the indicative customs and tax treatment reported for 2025/2026. Actual charges depend on tariff classification, exemptions and the legal status of preferential trade arrangements [19][36][38].

*Table 10 – Kenya: import charges applicable*

| Charge | Indicative national treatment (2025/2026) |
|---|---|
| Import duty – ACs (HS 8415) | Generally around 25% under the EAC Common External Tariff, depending on the HS subheading [36]. |

| Charge | Indicative national treatment (2025/2026) |
|---|---|
| Import duty – chillers, industrial refrigeration | Between 0% and 25% depending on the HS subheading and equipment classification [36]. |
| Import duty – cold chain equipment (cold rooms, commercial refrigeration) | Between 0% and 25%; consumer appliances are commonly treated differently from industrial equipment [36]. |
| Import duty – passive cooling components (insulation, shading, glazing, ventilation) | Varies by material and HS code [36]. |
| Import duty – smart controls, BMS, sensors | Commonly between 10% and 25%, depending on classification [36]. |
| VAT | 16% on the customs value plus applicable duty and other taxes [36]. |
| Import Declaration Fee (IDF) | Reported in the source used as 3.5% of import value; the rate has changed over time [36]. |
| Railway Development Levy (RDL) | 2% of customs value [36]. |
| Port and logistics costs | Additional costs include port handling, clearing-agent fees, storage and demurrage, PVoC charges, inspection and inland transport [19]. |
| Solar and renewable incentives | Solar cells and modules may qualify for duty or VAT relief. Bundled systems containing batteries, inverters or cooling equipment can receive different tariff treatment [36]. |
| Exemptions | No general exemption applies to externally financed cooling equipment; waivers are granted only in specific cases [19]. |
| EU–Kenya EPA | Entered into force in July 2024; implementation was stayed by an interim East African Court of Justice order in November 2025 pending determination of Reference No. 10 of 2024 [38]. |

# Behavioural Context

Demand for cooling in Kenya is shaped by factors that go beyond thermal need alone. Cooling retains strong associations with social status, and air conditioning units are sometimes installed for prestige reasons even where passive cooling would be adequate, a dynamic that must be factored into grid infrastructure planning [27]. Women face disproportionate exposure to heat-related risk, both through domestic tasks in poorly ventilated housing and through documented health impacts during pregnancy and the peripartum period [39][4]. More broadly, cooling is undergoing a rapid perception shift from luxury good to necessity as temperatures rise, though the market continues to be dominated by low-efficiency imported equipment [40].

Together, the geographic, demographic, economic and regulatory factors outlined in this section define the structural conditions within which cooling demand in Kenya operates. High ambient temperatures, rapid urbanisation, limited grid reliability and constrained household purchasing power shape the scale, location and technology profile of cooling demand. The following sections examine these patterns across healthcare, education and the food cold chain.

# Tertiary-Sector Cooling

## Healthcare

### System infrastructure and facility inventories

Kenya's health system is devolved, with responsibilities distributed between the national government and county governments [41]. Services are classified through the Kenya Essential Package for Health (KEPH), a six-level framework extending from community and primary-care services to national referral hospitals [42].

The facility breakdown by KEPH category, with current counts and bed capacities, is set out in Table 11.

*Table 11 – Kenya: healthcare facilities classification*

| Healthcare Facility Type | Description | Facilities | Total capacity<br>Hospital beds + cots | Average capacity<br>Hospital beds + cots |
|---|---|---|---|---|
| Community / Basic Healthcare Facility | KEPH ≤ 2<br>Hospital beds ≤ 50 | 8,699 [43] | 25,227 [43] | 2.9 [43] |
| Small district hospital | KEPH ≥ 3<br>50 < Hospital beds ≤ 150 | 152 [43] | 12,495 [43] | 82.2 [43] |
| Medium hospital | KEPH ≥ 3<br>150 < Hospital beds ≤ 300 | 61 [43] | 12,621 [43] | 206.9 [43] |
| Large hospital | KEPH ≥ 3<br>300 < Hospital beds ≤ 500 | 13 [43] | 4,943 [43] | 380.2 [43] |
| Referral / Tertiary sector hospital | KEPH ≥ 3<br>Hospital beds > 500 | 7 [43] | 5,629 [43] | 804.1 [43] |

Key structural imbalances emerge clearly from this distribution: 8,699 community-level facilities represent approximately 97.4% of the 8,932 facilities listed in Table 11 and account for about 41.4% of the reported bed-and-cot capacity. The remaining 233 hospitals above the 50-bed threshold therefore hold approximately 58.6% of capacity. This concentration of inpatient capacity in a small number of larger facilities creates significant access barriers in peri-urban and rural areas. As illustrated in Figure 5, the contrast with more developed health systems is pronounced, as Kenya records approximately 1.1 beds per 1,000 inhabitants against a global average of 3.3 [44].

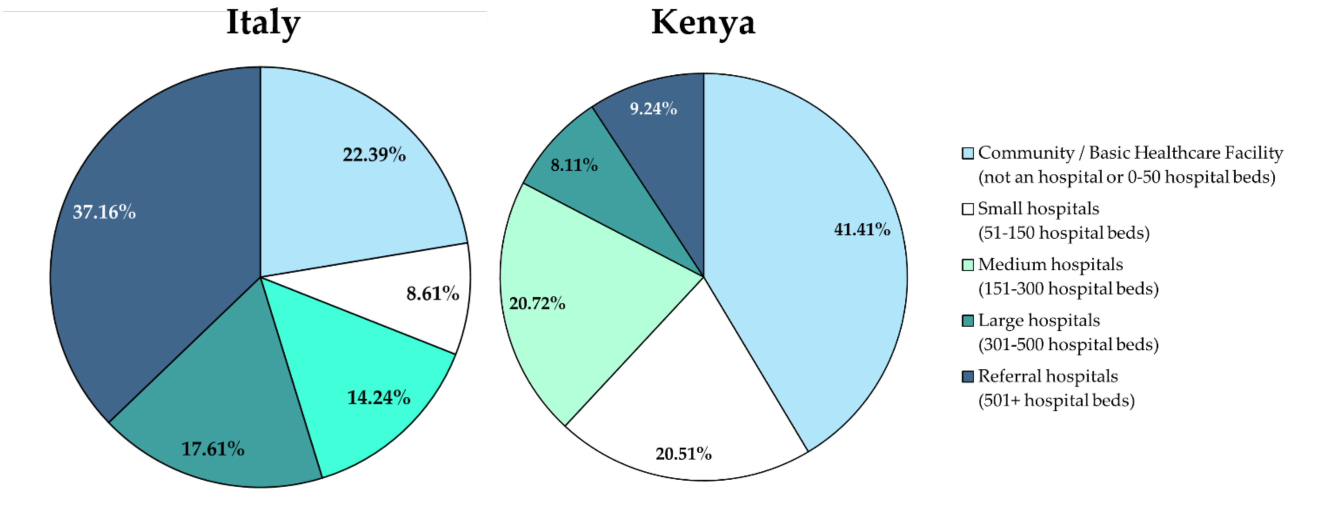



*Figure 5 – Kenya vs Italy: facilities distribution [43][45]*

The geographic distribution of facilities relative to thermal stress is shown in Figure 6. Areas with the highest cooling demand frequently coincide with areas where healthcare infrastructure is most constrained, indicating that thermal conditions will be an increasingly important feature of future health-system capacity.

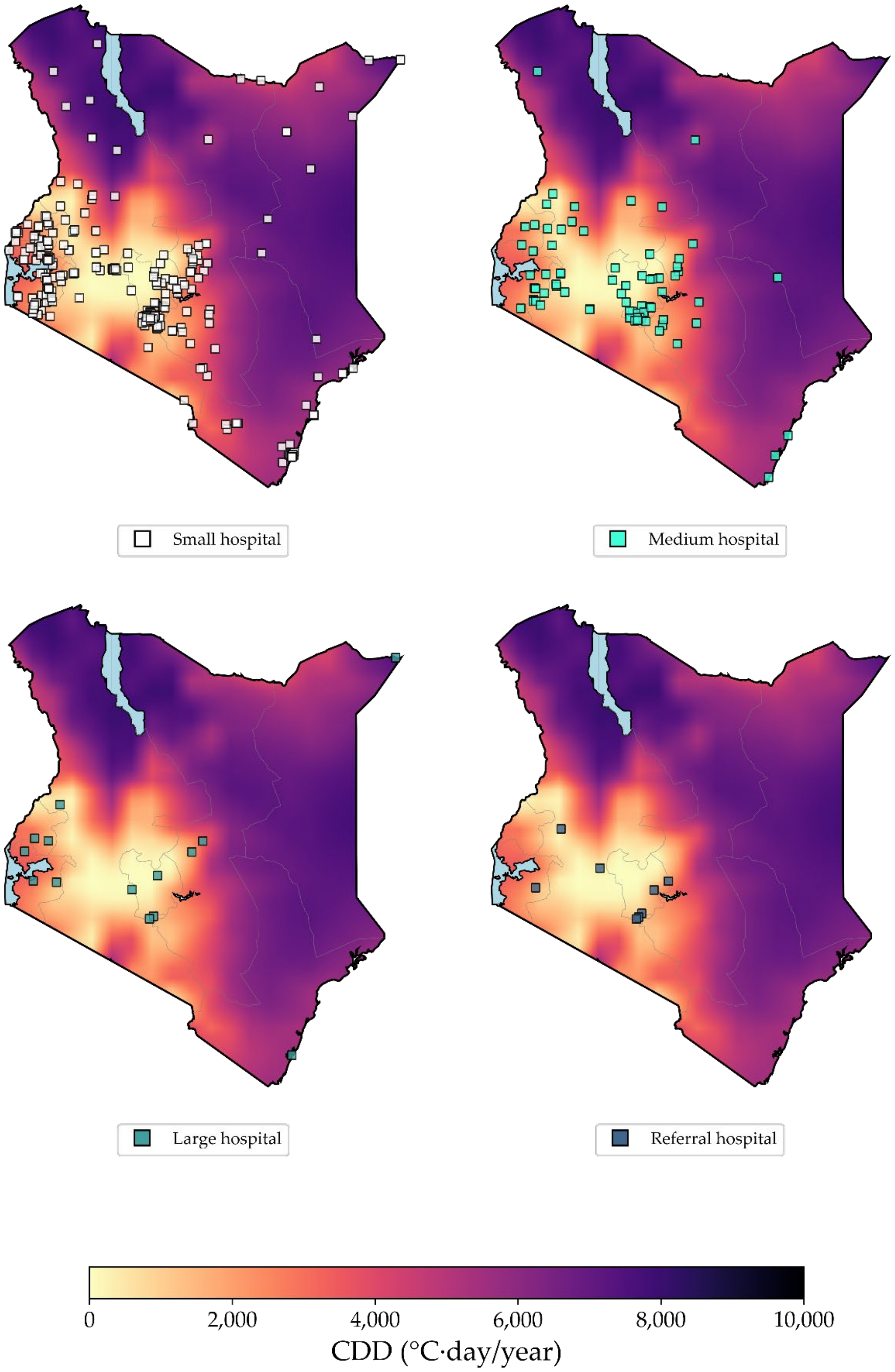



*Figure 6 - Kenya hospital facilities location vs cooling degree days 18°C distribution [2][43]*

## The cooling deficit and clinical consequences

Cooling is an operational enabler, not a comfort option. Its absence has documented consequences across three domains, summarised in Table 12.

*Table 12 – Kenya: healthcare cooling applications*

| Domain | Impact | Evidence / response |
|---|---|---|
| Vaccine cold chain (2 – 8 °C) | Unreliable electricity at approximately 30% of government facilities, together with legacy LPG refrigeration, creates chronic risk to vaccine potency [4] | >3,000 replacement units deployed via Gavi CCEOP; Solar Direct Drive (SDD) selected for off-grid resilience |
| Medical storage & labs | Pharmaceuticals, blood products, diagnostic reagents require uninterrupted 24h climate control [46] | Controlled storage and distribution conditions are required at facility and distribution levels [46] |
| Clinical thermal comfort | Heat episodes correlate with increased hospital admissions in Nairobi, Mombasa, Kisumu [30]. 'Unbearably hot' conditions in Kilifi County obstetric facilities [39]. Expanding malaria range into highlands increases inpatient load [47]. | Neonates, elderly, peripartum women are most affected [48] |

Where LPG-based refrigeration remains in use as a backup to grid electricity, failure risks are compounded by conditions specific to remote facilities. Fuel-supply interruptions, limited local maintenance capacity and inadequate temperature monitoring can allow faults or cold-chain breaks to persist undetected [49][4][50].

## Infrastructure demand projections

The projection preserves the current facility-type ratios and scales the 2024 stock to the population levels used in Figure 7. The scenario assumes an increase of approximately 9.9% by 2030 (from 56.4 million to about 62 million people) and 46.7% by 2050 (to about 82.7 million). The 2050 value is an explicit scenario population level rather than a mechanical compounding of the current 2.0% annual growth rate. The results represent a floor scenario that maintains current, already constrained facility ratios rather than a health-system development target [6][7][43].

*Additional facilities = current facility count × (scenario population / 2024 population − 1), rounded to whole facilities*

Even maintaining current and already inadequate facility ratios, population growth alone will require significant additional hospital infrastructure. The minimum number of new facilities needed by 2030 and 2050 is illustrated in Figure 7.

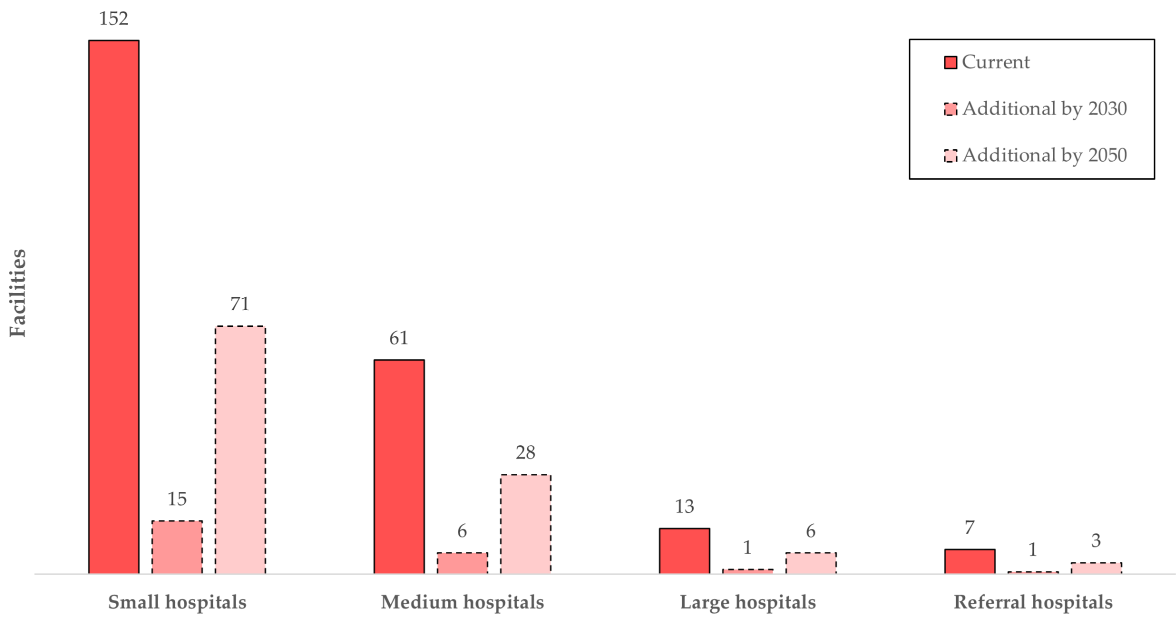



*Figure 7 – Kenya: current and additional facility number by size [7][43]*

## Current market conditions and technology

The current technology baseline in Kenya's healthcare cooling sector reflects a market at an early stage of transition, with a predominance of low-efficiency equipment and a refrigerant mix still weighted toward higher-GWP options. Key indicators are summarised in Table 13.

*Table 13 – Kenya: healthcare cooling technology indicators*

| Indicator | Value | Source |
|---|---|---|
| Medical refrigerators in service | approx. 8,342 units | [24] |
| New units installed since 2016 (Gavi CCEOP) | approx. 3,082 | [49] |
| Dominant AC type in clinical settings | Single-split (87% of market) | [24] |
| Low-efficiency fixed-speed units | approx. 90% of installed base | [24] |
| R22 share in installed ACs (2018 baseline) | approx. 27% | [24] |
| Dominant AC refrigerant (new units) | R410A, transitioning to R32 | [24] |
| Target refrigerant (hospital chillers) | R290, $NH_3/CO_2$ | [16] |
| Target refrigerant (medical refrigerators) | R-600a (isobutane) | [16] |

Despite the dominance of split units, the centralised chiller segment is growing. Figure 8 illustrates the projected sales trend in centralised chillers across clinical settings, reflecting the gradual transition away from split AC dominance toward more integrated cooling solutions.

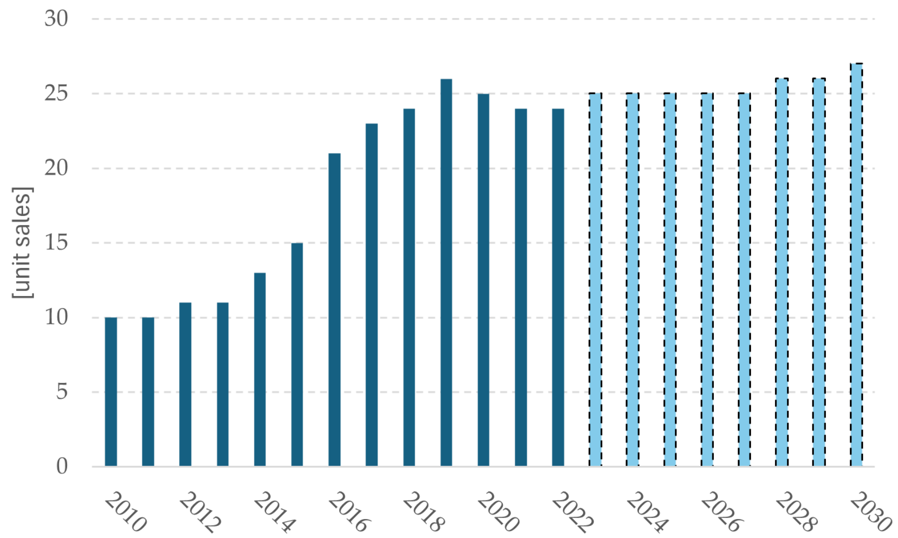



*Figure 8 – Kenya: centralized chillers estimated unit sales [24]*

## Energy implications

For the current stock of hospital facilities with more than 50 beds, applying the serviced-hospital benchmarks in Table 14 gives total hospital electricity consumption of approximately 242 GWh/yr, of which cooling accounts for about 121 GWh/yr. This is not observed current consumption and it does not include the additional facilities shown in Figure 7. It represents the order of magnitude that would arise if the existing hospital stock above the 50-bed threshold were fully serviced at the assumed benchmark levels.

Hospital energy consumption is represented through a bed-based screening proxy because facility-level metered data are not available for the national stock. Hospital benchmarking studies show that energy use varies materially with floor area, services, climate, occupancy and mechanical-system configuration, and that bed-based indicators are less reliable than area-based indicators. Accordingly, the values in Table 14 are explicit scenario parameters used to estimate an order of magnitude, not measured Kenyan benchmarks [51][52]. The approach is applied only to hospitals above the 50-bed threshold and does not estimate whole-facility HVAC loads for health posts, dispensaries or small clinics, whose priority cooling needs are more appropriately represented through vaccine and medical cold-chain resilience.

The corresponding energy consumption values used, along with their respective references and explanation, are presented in Table 14:

Indirect emissions use the national grid emission factor reported in the electricity-system section. Diesel backup is treated as a qualitative sensitivity rather than added to the central estimate because facility-level generator runtime and fuel use are not consistently available. Direct refrigerant emissions use the refrigerant distribution and chiller service-emission factor reported in the Kenya RAC inventory [24], combined with the explicit plant-size and charge assumptions reported in Table 15. These assumptions define a serviced-stock screening scenario for larger hospitals rather than an inventory of observed facility emissions.

*Table 14 – Healthcare screening energy parameters*

| Healthcare Facility Type | Level | Hospital electricity [kWh/bed·yr] | Cooling electricity [kWh/bed·yr] | Notes |
|---|---|---|---|---|
| Small district hospital | 1 | 4,600.00 | 2,300.00 | Lower screening parameter for smaller hospitals. It is a model assumption used for order-of-magnitude estimation, not a measured Kenyan benchmark; hospital benchmarking literature indicates substantial variation with services, floor area and climate [51][52]. |
| Medium hospital | 2 | 6,515.90 | 3,257.95 | Central screening parameter for medium hospitals. It is a model assumption used for order-of-magnitude estimation, not a measured Kenyan benchmark [51][52]. |
| Large hospital | 3 | 8,200.00 | 4,100.00 | Upper screening parameter for larger hospitals. It is a model assumption intended to represent greater service intensity and cooling demand, not a measured Kenyan benchmark [51][52]. |
| Referral / Tertiary sector hospital | 4 | 10,988.00 | 5,494.00 | High-service screening parameter for referral and tertiary hospitals. It is a model assumption intended to reflect greater technological and clinical complexity, not a measured Kenyan benchmark [51][52]. |

Facility-level GHG emissions are assessed as the sum of indirect contributions (electricity consumption) and direct contributions (refrigerant leakage).

Indirect emissions are calculated as the product of cooling electricity consumption and the national grid emission factor. No diesel adjustment is applied to the central estimate; backup generation is discussed separately because the available evidence that approximately 30% of government health facilities lack reliable electricity does not provide generator runtime or fuel consumption by facility [4].

Direct emissions are modelled from the facility stock and the screening assumptions in Table 15. The assumed plant size and specific charge are not observed national averages; they are used to translate the serviced-stock scenario into an indicative installed charge. The 22% annual service-emission factor and the refrigerant distribution are taken from the Kenya RAC inventory [24].

*Table 15 – Healthcare cooling-plant screening assumptions*

| Healthcare Facility Type | Level | Typical cooling system | Average plant size assumed [MW] | Specific refrigerant charge [$kg_{refr,charge}/kW_{installed}$] | Service emission factor $\left[\frac{kg_{refr,leak}}{kg_{refr,charge}\cdot year}\right]$ |
|---|---|---|---|---|---|
| Small district hospital | 1 | Chilled water plants [24] | 0.71 (model assumption) | 0.14 (model assumption) | 22% [24] |
| Medium hospital | 2 | Chilled water plants [24] | 2.5 (model assumption) | 0.14 (model assumption) | 22% [24] |
| Large hospital | 3 | Chilled water plants [24] | 5.9 (model assumption) | 0.14 (model assumption) | 22% [24] |
| Referral / Tertiary sector hospital | 4 | Chilled water plants [24] | 16.6 (model assumption) | 0.14 (model assumption) | 22% [24] |

Using the refrigerant distribution reported for centralised chiller installations [24], a weighted average GWP of approximately 2,280 and the 0.274 $kgCO_2/kWh$ electricity-consumption factor [20][21], the serviced current-stock scenario gives approximately 33.2 $ktCO_2/yr$ of indirect cooling emissions and 31.8 $ktCO_2eq/yr$ of modelled direct refrigerant emissions, for a combined total of about 65.0 $ktCO_2eq/yr$. These values are scenario results rather than observed facility emissions and are sensitive to the explicit plant-size and charge assumptions in Table 15.

## Structural constraints

Despite a favourable policy environment, several structural constraints limit the diffusion and reliable operation of efficient cooling across the healthcare sector. The main constraints are identified in Table 16.

*Table 16 – Kenya: barriers to the deployment of cooling technologies in the healthcare sector*

| Barrier | Detail |
|---|---|
| Grid instability | approx. 3 outages/month, each exceeding 3h [18]; 30% of government health facilities lack reliable electricity [4] |
| LPG/diesel fallback | Electricity access at govt health facilities grew only 1 pp between 2016–2019; continued dependence on costly, high-emission backup [4][53] |
| RAC technician shortage | Dependence on specialist technicians; high repair cost and long downtime [4][27] |
| High upfront capex | Limits access to high-efficiency equipment in smaller facilities and county health systems [4]. |

## Technology directions in the NCAP

The National Cooling Action Plan identifies technology directions for the principal healthcare cooling applications. These policy directions are summarised in Table 17.

*Table 17 – Kenya: technology pathway for healthcare cooling applications*

| Application | Technology direction identified in the NCAP |
|---|---|
| Clinical HVAC (general wards) | Inverter-driven splits, VRF, mini-chillers [16] |
| ICU / high-dependency units | Semi-centralised systems with heat recovery, enthalpic recuperators, TES; target 21–23 °C, 40–60% RH [16] |
| Medical storage / cold rooms | High-efficiency units, R290 or $CO_2$, digital monitoring, 2–8 °C continuous [16] |
| Vaccine cold chain (off-grid / grid-unstable) | Solar Direct Drive (SDD) refrigerators with battery/thermal storage [16] |
| Building envelope (new / retrofit) | Cool roofs, natural ventilation, shaded envelopes [16] |
| Service and delivery models | Cooling as a Service, on-bill financing and externally supported vaccine cold-chain programmes are identified as emerging delivery mechanisms [16]. |

## Sector summary

The principal barriers and enabling conditions in healthcare cooling are summarised in Table 18.

*Table 18 – Kenya: healthcare cooling quick summary*

| Dimension | Barriers | Enablers |
|---|---|---|
| Energy infrastructure | Grid instability averaging 3 outages per month; approximately 30% of government facilities lack reliable electricity; continued LPG and diesel fallback [18][4]. | 76.2% national electrification rate<br>Growing SDD deployment<br>NCAP hybrid micro-grid support [13][16] |

| Dimension | Barriers | Enablers |
|---|---|---|
| Technology & maintenance | Approximately 90% of installed ACs are low-efficiency fixed-speed units; shortages of RAC technicians and high specialist repair costs [24][4][27]. | Ongoing transition to inverter<br>VRF and mini-chiller systems<br>R290 and $CO_2$ adoption in new cold rooms<br>NCAP equipment incentives. [16] |
| Affordability and capital access | High upfront capital costs limit adoption in smaller facilities; concessional finance remains limited [4]. | Gavi CCEOP support, health-electrification programmes and emerging service-based models [49][53][16] |
| Regulatory & Policy | R22 still present in approximately 27% of installed ACs<br>Uneven enforcement of phase-out timelines [24][16] | National R22 ban target 2026<br>NCAP integrated policy framework<br>MoH cold chain optimisation programme [16][17] |
| Demand & demography | Population growth requires a minimum of 71 new small hospitals and 28 medium hospitals by 2050 at current facility ratios [7][43] | Long-term growth in the hospital estate; approximately 121 GWh/yr of cooling demand for the serviced current stock above 50 beds, excluding the additional facilities in Figure 7; alignment with the national cooling and climate-policy framework [16]. |

# Education

## System structure and context

Kenya's education system serves one of the youngest populations in the world, with approximately 36% of the total population falling within the school-age range of 4 to 17 years. The system is structured across primary, secondary, and tertiary levels, with the public sector accounting for 87.6% of secondary schools. Primary enrolment has reached near-universal coverage, yet learning outcomes remain uneven, partly due to the thermal conditions in which teaching takes place. Average class sizes of 50 students, peaking at 80 in some public schools, generate significant internal heat loads that compound the effect of solar gain through inadequately insulated building envelopes. The geographic distribution of education facilities relative to thermal stress is shown in Figure 9. [54][55]

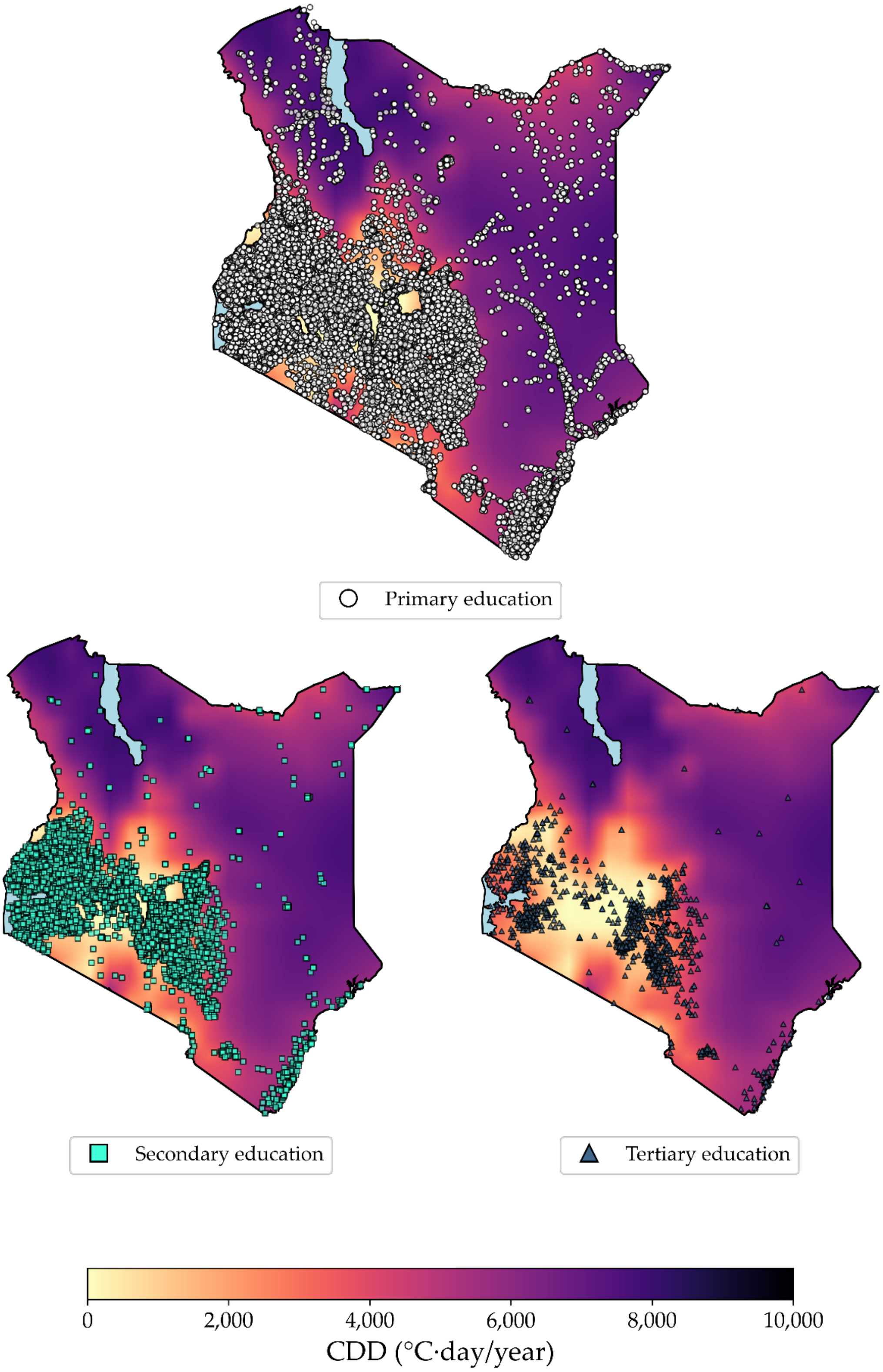



*Figure 9 – Kenya: Education facilities location vs cooling degree days 18°C distribution [2][56]*

As in the healthcare sector, the areas of highest cooling demand coincide with those where infrastructure is most constrained and where construction of new facilities is most urgently needed.

Key sector indicators are summarised in Table 19.

*Table 19 – Kenya: education sector key indicators*

| Indicator | Value | Source |
|---|---|---|
| School-age population (4–17 yrs) | approx. 36% of total population | [54] |
| Primary enrolment rate | Near-universal | [55] |
| Average class size (public) | 50; peaks at 80 | [54] |
| Public sector share of secondary schools | 87.6% | [54] |
| Non-university institutions off-grid | approx. 20% | [57] |

## The thermal problem

Two compounding factors create severe thermal stress in Kenyan schools. A survey of 100 schools under the Kenya National Energy Efficiency and Conservation Strategy found widespread overheating associated with insufficient natural ventilation and exposed iron-sheet roofing [4]. National sources do not provide an inventory of air-conditioning equipment by education level. The NCAP therefore identifies the assessment of cooling demand in educational buildings as an area requiring further development [16].

Broader review evidence links elevated classroom temperature with impaired student performance [58]. Evidence from comparable tropical African classrooms also shows that roofing and construction materials can materially affect indoor temperatures [59]. Regional disparities are acute: ASAL counties such as Turkana and Mandera combine high thermal stress with low secondary enrolment and constrained electricity access [54][57].

## Market trajectory

Mechanical cooling adoption in education remains formative. The NCAP reports air-conditioning penetration of about 30% for the commercial sector as a whole, but this value is not education-specific and should not be transferred directly to schools [16]. The near-term market is more likely to be concentrated in universities, technical institutions, administrative spaces, computer laboratories and a limited number of urban or hot-climate secondary schools. GIZ projects the national stock of non-ducted split ACs to rise from about 1.00 million units in 2025 to 1.17 million in 2030, while multi-split and VRF outdoor units increase from about 14,600 to 34,300 [24]. Figure 10 shows the corresponding national sales trajectory across all sectors.

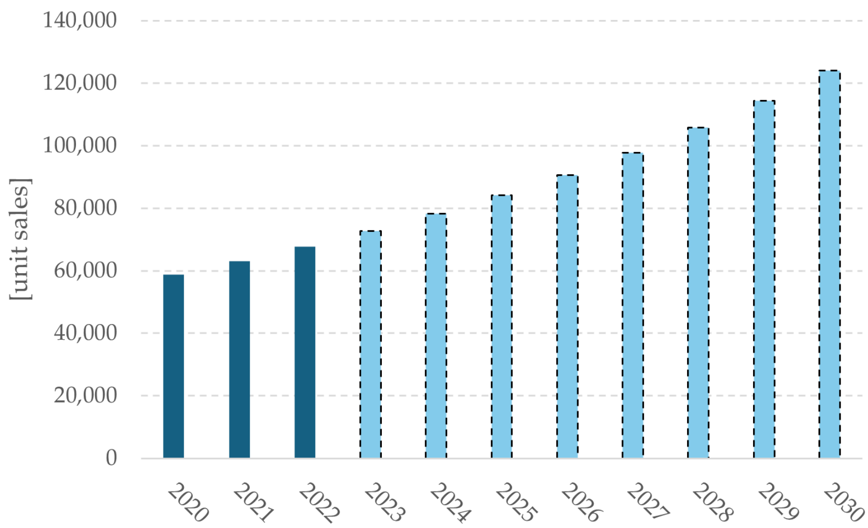



*Figure 10 – Estimated unit sales of splits and multi-splits systems in Kenya, 2020-2030 [24]*

Key market indicators are summarised in Table 20.

*Table 20 – Kenya: education cooling technologies indicators*

| Indicator | Value | Source |
|---|---|---|
| National market benchmark | Commercial-sector AC penetration is estimated at approximately 30%; this is an upper contextual benchmark, not a school-sector observation | [16] |
| Indicative current education cooling demand | Approximately 14.5 GWh/yr; about 0.9% of commercial and public-services electricity | [16][24][54][57][4][60] |
| Medium-term adoption scenario | Approximately 56.0 GWh/yr; about 3.3% of commercial and public-services electricity | [16][24][54][57][4][60] |
| Equipment-stock cross-check | Approx. 12,704 non-university split units in the current scenario and 47,991 in the medium-term scenario, equal to about 1.3% of projected 2025 and 4.1% of projected 2030 national split stock | [24] |

## Demand Estimation Methodology

Cooling electricity is estimated through two screening scenarios because Kenya does not publish an education-specific inventory of installed AC equipment. The first is an indicative current-use scenario, intended to represent the small existing base of mechanically cooled educational spaces. The second is a medium-term adoption scenario, representing targeted expansion by around 2030 rather than universal classroom cooling. Both scenarios retain the same education activity data and equipment-performance assumptions, while varying adoption and equivalent full-load use.

For primary and secondary education, the model uses classroom counts derived from Ministry of Education enrolment and average class-size data. Rather than applying the earlier peak-load calculation uniformly across all climates, the scenario uses the average Kenyan non-ducted split AC reported by GIZ: 5.59 kW of cooling capacity, COP 3.33 and 1.76 kg of refrigerant charge [24]. Two units are assumed for a 34-pupil primary classroom and three units for a 53-pupil secondary classroom. These configurations are screening assumptions, not design prescriptions; actual system size depends on building form, ventilation, humidity, shading and passive-cooling measures.

*Table 21 – Kenya: technical parameters used in the education cooling scenarios*

| Parameter | Value | Reference |
|---|---|---|
| Average non-ducted split cooling capacity | 5.59 kW per unit | [24] |
| Average split COP | 3.33 | [24] |
| Average initial refrigerant charge | 1.76 kg per unit | [24] |
| Primary classroom configuration | 2 split units; 11.18 kW cooling and 3.36 kW electrical | Scenario assumption; class size from [54] |
| Secondary classroom configuration | 3 split units; 16.77 kW cooling and 5.04 kW electrical | Scenario assumption; class size from [54] |

The education activity base and resulting classroom-equivalent equipment configuration are reported in Table 22.

*Table 22 – Kenya: classroom characteristics*

| Level | Enrolment | Students per classroom | Approx. classrooms | Split units per classroom | Installed cooling capacity | Electrical capacity |
|---|---|---|---|---|---|---|
| Primary | approx. 8.15 million [54] | 34 [54] | approx. 239,600 | 2 | 11.18 kWth | 3.36 kWel |
| Secondary | approx. 6.70 million [54] | 53 [54] | approx. 126,400 | 3 | 16.77 kWth | 5.04 kWel |

Non-university tertiary institutions are treated as secondary-classroom equivalents. Their cooled-space share is set at 8% in the current scenario and 25% in the medium-term scenario, with 300 and 400 equivalent full-load hours per year respectively. University demand retains the existing full-service benchmark of 40.1 GWh/yr, scaled to a 20% cooled-space share in the current scenario and 45% in the medium-term scenario [24][60].

For basic education, adoption and use are differentiated by climatic zone. The utilisation percentage is defined as an equivalent full-load share of the 1,560-hour school year, so it already accounts for compressor cycling, part-load operation and days when systems are installed but not required. Current adoption is kept below 5% in every primary-school zone and below 5% in most secondary-school zones, reflecting the absence of a national school AC programme, incomplete electricity access and the emphasis on passive cooling in national assessments [16][57][4]. The medium-term scenario allows targeted expansion in the coast and ASAL regions while remaining well below universal coverage and below the 30% current commercial-sector benchmark on a nationally weighted basis [16].

*Table 23 – Kenya: education cooling adoption and equivalent-use assumptions*

| Climatic zone | Population share | Indicative current-use scenario | Medium-term scenario |
|---|---|---|---|
| Hot/humid coastal | 6.5% [22] | Primary 2%; secondary 5%; 25% equivalent full-load use | Primary 10%; secondary 20%; 35% equivalent full-load use |
| Temperate highlands | 55.6% [22] | Primary 0.5%; secondary 1.5%; 10% equivalent full-load use | Primary 1%; secondary 4%; 15% equivalent full-load use |
| Arid and semi-arid (ASAL) | 37.9% [22] | Primary 1%; secondary 3%; 25% equivalent full-load use | Primary 6%; secondary 12%; 35% equivalent full-load use |
| **National weighted result** | 100% [22] | Adoption: primary 0.79%, secondary 2.30%; joint adoption-use factors 0.155% and 0.449% | Adoption: primary 3.48%, secondary 8.07%; joint adoption-use factors 1.107% and 2.380% |

The current scenario implies nationally weighted mechanical-cooling adoption of 0.79% of primary classrooms and 2.30% of secondary classrooms. The medium-term scenario increases these shares to 3.48% and 8.07% respectively. The resulting non-university equipment stocks are approximately 12,704 and 47,991 split units.

These correspond to about 1.3% of the national split-AC stock projected by GIZ for 2025 and 4.1% of the projected 2030 stock, providing an external plausibility check [24].

*Basic-education energy [GWh] = Σzone (classrooms × zone share × adoption × split units per classroom × unit electrical input × 1,560 h/yr × equivalent full-load share) / $10^6$.*

For universities, the existing full-service estimate based on 562,925 enrolled students and 630 annual occupancy hours is retained as a capacity benchmark and scaled by the assumed cooled-space share [60]. The resulting electricity demand is approximately 14.5 GWh/yr in the indicative current-use scenario and 56.0 GWh/yr in the medium-term scenario. Figure 11 shows the subsector breakdown.

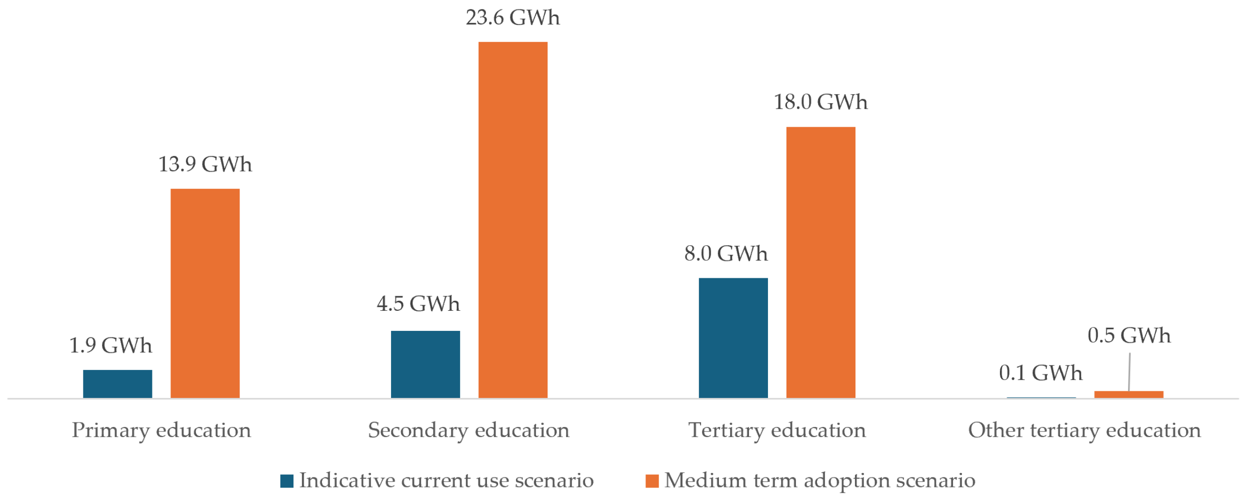



*Figure 11 – Kenya: estimated education cooling electricity by subsector and scenario [16][24][54][57][4][60]*

The indicative current-use scenario totals approximately 14.5 GWh/yr, around 0.9% of Kenya's commercial and public-services electricity consumption of 1,688 GWh/yr [61]. The medium-term scenario totals approximately 56.0 GWh/yr, or 3.3% of that benchmark. Neither value is an observed sector total: the first is a stock-consistent estimate of present use, while the second represents targeted adoption in hot-zone and tertiary facilities rather than universal classroom air conditioning.

## Emissions Estimation

Indirect emissions are calculated using the report-wide electricity-consumption factor of 0.274 $tCO_2$/MWh [20][21], giving 3.99 $ktCO_2$/yr in the current-use scenario and 15.37 $ktCO_2$/yr in the medium-term scenario. Direct emissions for non-university systems use the GIZ average split charge of 1.76 kg, a 10% annual service leakage factor and the weighted refrigerant GWP in Table 24 [24]. University direct emissions are scaled from the full-service chiller estimate in proportion to the assumed cooled-space share.

*Table 24 – Kenya: split & multi-split systems refrigerant adoption share*

| Refrigerant | Market share | GWP (AR4) |
|---|---|---|
| R-410A | 80% [24] | 2,088 [24] |
| R-407C | 20% [24] | 1,770 [24] |
| Weighted average GWP | 100% [24] | 2,024 [24] |

At the weighted GWP of 2,024, each average split unit corresponds to approximately 0.356 $tCO_2eq$/yr of service leakage under the 10% assumption. The emissions results are summarised in Table 25. These are scenario estimates; actual leakage depends on equipment age, refrigerant choice and maintenance practice [24].

*Table 25 – Kenya: education cooling emissions by scenario*

| Emission component | Indicative current-use scenario [$ktCO_2eq$/yr] | Medium-term scenario [$ktCO_2eq$/yr] |
|---|---|---|
| Indirect emissions – electricity | 3.99 [20][21] | 15.37 [20][21] |
| Direct emissions – non-university split systems | 4.53 [24] | 17.10 [24] |
| Direct emissions – university systems | 1.97 [24] | 4.44 [24] |
| Total estimated emissions | 10.49 [20][21][24] | 36.91 [20][21][24] |

Total estimated cooling-related emissions are approximately 10.5 $ktCO_2eq$/yr in the indicative current-use scenario and 36.9 $ktCO_2eq$/yr in the medium-term scenario. The medium-term value is about 5.3% of the reported 700 $ktCO_2$ emitted by Kenya's commercial and public-services sector [60]. The results also show that refrigerant choice and servicing quality remain important as adoption expands.

## Market segmentation

Kenya's education cooling landscape divides into two structurally distinct segments with different infrastructure and technology profiles.

The first segment comprises rural and off-grid schools, estimated at approximately 20% of non-university institutions and concentrated in ASAL regions [57]. Mechanical cooling remains rare in this segment. Passive measures documented in Kenya and comparable tropical settings include reflective or insulated roofs, cross- and stack-ventilation, external shading, higher-thermal-mass construction, evaporative approaches and vegetation. Field studies report indoor temperature reductions of up to 15°C under favourable configurations [4][62]. Electricity access and operating cost remain the main limits on widespread mechanical cooling.

The second segment comprises universities, urban secondary schools and administrative facilities with more reliable grid access. Multi-split and VRF systems are increasingly relevant, within the MEPS framework under KS 2463:2019 and Kenya's wider transition toward lower-GWP refrigerants [15][17]. Projected growth of 126% in multi-split and VRF sales by 2030 indicates that the installed technology baseline is still being formed [24]. Passive design, solar-powered ventilation and efficient active cooling are increasingly combined in institutional buildings.

## Sector summary

The principal barriers and enabling conditions in education cooling are summarised in Table 26.

*Table 26 – Kenya: education sector cooling quick summary*

| Dimension | Barriers | Enablers |
|---|---|---|
| Energy infrastructure | approx. 20% off-grid<br>Grid unreliability in connected schools<br>ICT and cooling competing for limited power [57][18] | Electrification programmes; abundant solar resource<br>DLP infrastructure as co-investment entry point [57][16] |

| Dimension | Barriers | Enablers |
|---|---|---|
| Building stock | Lightweight metal roofing and insufficient ventilation contribute to overheating [4][59] | NCAP identifies passive cooling as primary sector strategy<br>National Building Code 2024 strengthens thermal provisions<br>Up to 15 °C reduction demonstrated [4] [16][63] |
| Affordability and delivery capacity | Mechanical cooling remains beyond most school budgets; investment cycles are often dependent on public programmes or development partners; local passive-design capacity is limited [4]. | Public education budgets and development-finance programmes are potential channels; no dedicated national cooling-finance mechanism for schools was identified [16]. |
| Market maturity | Mechanical cooling remains uncommon in basic education; no national education-specific installed-stock inventory is available [16][4]. | Indicative current demand approximately 14.5 GWh/yr; medium-term adoption approximately 56.0 GWh/yr. Projected growth in national split and multi-split stocks supports gradual institutional uptake [24]. |
| Regulatory | No thermal comfort standard in current code<br>Limited MEPS enforcement capacity [15][17] | MEPS in force (KS 2463:2019)<br>NCAP roadmap<br>Kigali Amendment accelerating low-GWP adoption [15][16][17] |

# Food Cold Chain

## Structure of the national food cold chain

Kenya's food cold chain is not a single, uniform system. Export-oriented horticulture and floriculture use comparatively formalised packhouses, quality-control procedures and temperature-managed logistics, while most domestic value chains remain fragmented and depend on short, largely uncooled movements through small traders and open markets. Cold-chain access is therefore concentrated in high-value export and formal processing channels, with substantially lower penetration in domestic first-mile and wholesale distribution [12][64].

Kenya's Postharvest Management Strategy for 2024-2028 estimates that around 30% of food is lost between production and consumption, with higher losses reported in some commodity chains. It identifies inadequate storage, transport, cold-chain management, reliable energy, standards and technical skills among the main contributing factors [65]. The national percentage is an aggregate policy indicator rather than a uniform loss rate for every commodity or region.

*Table 27 – Kenya: export-oriented and domestic cold-chain characteristics*

| Dimension | Export-oriented systems | Domestic and regional systems |
|---|---|---|
| Market organisation | More formal packhouses, quality assurance and coordinated logistics serving high-value markets [12][64]. | Fragmented chains dominated by small producers, traders and informal markets, with limited access to first-mile cooling [12][64]. |
| Priority products | Fresh horticulture and floriculture requiring pre-cooling, grading and temperature control. | Fruits and vegetables, dairy, fisheries and other perishables identified as priority value chains [64][65]. |
| Typical cooling function | Rapid field-heat removal, controlled storage, temperature monitoring and compliant transport. | Low-cost pre-cooling, milk chilling, ice production, modular cold rooms and insulated local transport. |
| Commercial logic | Quality retention, rejection avoidance and access to higher-value markets. | Loss reduction, longer marketing windows, aggregation and improved bargaining power. |

| Dimension | Export-oriented systems | Domestic and regional systems |
|---|---|---|
| Primary risk | Temperature excursions at handover points and inadequate redundancy. | Insufficient throughput, weak aggregation, high upfront cost and limited after-sales service. |
| Access and financing conditions | Commercial investment is concentrated in exporters, large processors and formal logistics operators [12][64]. | Smallholders, cooperatives and informal traders face limited collateral, seasonal throughput and high unit costs; shared-service and pay-per-use models are emerging [12][64]. |

## Main value chains and cooling nodes

Cooling functions are concentrated at first-mile horticulture aggregation points, dairy collection centres, fish landing sites, wholesale markets, export packhouses and logistics interfaces. Table 28 summarises the principal functions and constraints at these nodes.

*Table 28 – Kenya: principal cold-chain nodes and functions*

| Value-chain node | Current or emerging cooling functions | Main national constraints |
|---|---|---|
| First-mile horticulture aggregation | Shade and improved handling, forced-air or other pre-cooling, modular cold rooms, reusable crates and temperature logging [64][65]. | Highly seasonal and fragmented volumes; limited energy access; weak aggregation and variable links to buyers. |
| Dairy collection and cooperatives | Bulk milk chilling, hygienic collection systems, thermal storage and grid, solar or hybrid power [64]. | Around 80% of raw milk is traded informally with limited cooling; quality control and maintenance capacity vary widely [64]. |
| Fish landing sites and markets | Ice production, chilled storage, insulated boxes and temperature-controlled distribution [65]. | Dispersed landings, water and sanitation constraints, corrosion, seasonal catches and limited cold transport. |
| Wholesale and urban markets | Shared cold rooms, differentiated temperature zones, pay-per-use storage and digital inventory systems. | High product turnover, fragmented stallholders, uncertain occupancy and affordability constraints. |
| Export packhouses and logistics interfaces | Pre-cooling, cold storage, backup capacity, monitoring and temperature-managed transport. | Temperature excursions at handovers, dependence on logistics reliability and uneven access to refrigerated sea transport. |

## Logistics interfaces

The Port of Mombasa and the Standard Gauge Railway-linked inland container depots are important interfaces for temperature-sensitive trade. Kenya Ports Authority states that the Nairobi Inland Container Depot is directly linked to Mombasa and has capacity above 450,000 TEU per year, while Naivasha serves regional markets and the Rift Valley hinterland [66]. Secondary industry reporting attributes to KPA a total of 1,367 reefer plug points across Mombasa, Nairobi, Lamu and Naivasha; these figures are useful activity indicators but are not a substitute for terminal operating-system records [67].

*Table 29 – Kenya: logistics nodes relevant to the food cold chain*

| Node | Documented role | Cold-chain relevance and data limitation |
|---|---|---|
| Port of Mombasa | National maritime gateway; secondary reporting attributes 795 reefer plug points and 6,813 export reefer TEU in Q1 2024 to KPA [67]. | The quarterly throughput provides the principal public activity anchor. Annual seasonality, connected hours, plug occupancy and electricity-source shares are not reported. |

| Node | Documented role | Cold-chain relevance and data limitation |
|---|---|---|
| Nairobi Inland Container Depot | Rail-linked inland depot with stated throughput capacity above 450,000 TEU/yr [66]; secondary reporting attributes 336 reefer plug points to KPA [67]. | Important inland consolidation node. Public data do not isolate reefer movements, residence time or electricity consumption. |
| Lamu Port | Secondary maritime gateway; secondary reporting attributes 216 reefer plug points to KPA [67]. | Connection capacity is documented, but current refrigerated throughput and annual utilisation are not publicly disaggregated. |
| Naivasha Inland Container Depot | Rail-linked depot serving the Rift Valley hinterland [66]; secondary reporting attributes 20 reefer plug points to KPA [67]. | Potential interface for regional perishables; current reefer traffic, connected time and cold-store integration are not reported in detail. |
| County aggregation sites | First-mile nodes located near production areas, cooperatives and local markets [64][65]. | Large geographic potential, but throughput density, energy access, governance and service capacity differ substantially by county. |

## Estimated energy use and greenhouse-gas emissions

Kenya does not yet publish an integrated energy balance linking conditioned cold-store volume, equipment utilisation, industrial output, refrigerated-container movements, residence time and metered electricity use. The estimate below is therefore a transparent national screening envelope rather than an observed inventory. It covers formal milk chilling before processing, export-horticulture pre-cooling, third-party and production-area refrigerated warehousing, containerised reefer operation at Kenyan ports and inland depots, and process refrigeration inside formal food and beverage manufacturing. Retail display cabinets, household refrigeration, dedicated road-transport refrigeration units, informal ice production and direct refrigerant leakage remain outside the quantified boundary. Published cold-store and reefer benchmarks are used only where Kenya-specific metered data are unavailable [68][69], while food-loss emissions are kept separate because their accounting boundary differs from operational refrigeration emissions [70].

Reefer logistics. The public activity anchor is a Q1 2024 figure of 6,813 export reefer TEU reported by an industry association and attributed to KPA [67]. A simple annualisation gives 27,252 TEU/yr. Applying the published mean electrical draw of 2.7 kW per TEU [69] yields about 7.1 GWh/yr for four connected days and 12.4 GWh/yr for seven connected days. The four-to-seven-day interval is an explicit residence-time scenario rather than an observed national mean and spans port dwell, inland-depot residence and connected staging. A wider 20,000-35,000 TEU/yr sensitivity gives approximately 5-16 GWh/yr. Road transport refrigeration and diesel gensets are excluded because national vehicle activity and fuel-use data are unavailable.

Industrial food processing. The KNBS Census of Industrial Production reports electricity purchases of 951.6 GWh for formal food-product manufacturing and 137.0 GWh for beverage manufacturing in the 2017 reference year, or 1,088.6 GWh in total [71]. Kenya does not publish an end-use split for this electricity. The Kenya RAC inventory provides an independent national cross-check: its projection places the entire industrial-refrigeration subsector at approximately 0.15-0.20 TWh/yr around 2020-2025 [24]. Because that category is broader than food and beverage processing, it is not added separately. The 2022 U.S. Manufacturing Energy Consumption Survey assigns 24.6-26.8% of food- and beverage-industry net electricity to process cooling and refrigeration [72], but direct transfer would not reflect Kenya's industrial structure and technology penetration. The Kenyan estimate is therefore bounded at 10-17% of formal food and beverage electricity. This gives approximately 109-185 GWh/yr, rounded to 110-185 GWh/yr. The upper bound remains below the 200 GWh upper estimate for the broader national industrial-refrigeration subsector, while the lower bound leaves room for other industrial applications within the 150 GWh lower estimate. The KNBS base is not escalated beyond 2017 because a newer official subsector end-use balance is not available.

Refrigerated warehouses not represented by the per-capita proxy. The earlier 33,800 $m^3$ estimate is a simple demand proxy, not an asset census. Public evidence demonstrates material capacity outside that proxy: EEP Africa identifies more than 4,000 tonnes of existing and upcoming fresh-produce cold storage in production areas such as Meru and Nakuru [73]; the environmental documentation for the Tatu City facility describes up to 12,000 $m^2$ of cold-storage floor area and capacity for 15,000-20,000 pallets [74]; and the operator currently reports approximately 20,000 pallet positions across Tatu City and Mombasa [75]. Exact conditioned volume, overlap among these figures and the food/pharmaceutical allocation are not public. A reconciliation allowance of 70,000-140,000 $m^3$ is therefore used. It is obtained by applying an explicit 6-10 m effective conditioned-height sensitivity to the 12,000 $m^2$ facility footprint, then allowing for production-area assets and possible overlap. Applying the measured cold-store benchmark of 44.3-61.9 kWh/$m^3$·yr [68] gives approximately 3-9 GWh/yr. This is an engineering sensitivity range, not a claim that all unregistered facilities or their utilisation have been identified; the food-attributable share may be lower where mixed pharmaceutical storage is significant.

*Table 30 – Kenya: bounded estimate of food cold-chain electricity demand and emissions*

| Component | Activity basis and calculation | Estimated annual electricity / emissions |
|---|---|---|
| Formal milk chilling before processing | Milk production of approximately 6.0 Mt/yr [73]; around 20% enters the formal chain using chillers [64]; net chilling requirement of 25-30 kWh/t [76]. The calculation refers to collection and aggregation before factory processing. | 30-36 GWh/yr; approximately 8.2-9.9 kt$CO_2$/yr at 0.274 kg$CO_2$/kWh [20][21]. |
| Export-horticulture pre-cooling | Fresh fruit and vegetable production of approximately 7.7 Mt/yr [73], with exports equivalent to about 4% of domestic production [64]. Assessment load: 8.8-10.6 kWh/t for removal of field heat. | 2.7-3.3 GWh/yr; approximately 0.7-0.9 kt$CO_2$/yr [20][21]. |
| General refrigerated warehousing - base proxy | Urban population of approximately 16.9 million [6][9] multiplied by 0.002 $m^3$ per urban resident [64] gives about 33,800 $m^3$; specific electricity 44.3-61.9 kWh/$m^3$·yr [68]. | 1.5-2.1 GWh/yr; approximately 0.4-0.6 kt$CO_2$/yr [20][21]. |
| Additional warehousing not represented by the proxy | Reconciliation allowance of 70,000-140,000 $m^3$, informed by >4,000 t of production-area capacity [73], a 12,000 $m^2$ / 15,000-20,000-pallet facility description [74], and the operator-reported 20,000-pallet portfolio [75]. Applied intensity: 44.3-61.9 kWh/$m^3$·yr [68]. | Approximately 3-9 GWh/yr; approximately 0.8-2.5 kt$CO_2$/yr [20][21]. This is a bounded engineering allowance, not a national warehouse census. |
| Containerised reefer logistics in Kenya | 6,813 TEU in Q1 2024, reported by an industry association and attributed to KPA [67], annualised to 27,252 TEU/yr; 2.7 kW/TEU mean draw [69]; four-to-seven-day connected-period scenario covering port and inland logistics stages. | Central estimate: 7.1-12.4 GWh/yr; wider traffic sensitivity: approximately 5-16 GWh/yr. Central indirect emissions: approximately 1.9-3.4 kt$CO_2$/yr [20][21]. |
| Industrial food and beverage process refrigeration | KNBS formal-sector electricity: 951.6 GWh for food products and 137.0 GWh for beverages [71]. Refrigeration share bounded at 10-17%; cross-checked against the broader Kenya industrial-refrigeration projection of approximately 150-200 GWh/yr [24] and 24.6-26.8% U.S. process-cooling shares [72]. | Approximately 110-185 GWh/yr; approximately 30-51 kt$CO_2$/yr [20][21]. The 2017 activity base is not growth-adjusted. |
| Bounded national operational total | Gross sum of the components above. The categories are defined to reduce overlap: milk chilling is pre-processing, horticulture | Approximately 155-250 GWh/yr, equal to about 1.2-1.9% of national electricity production; approximately 43-69 |

| Component | Activity basis and calculation | Estimated annual electricity / emissions |
|---|---|---|
| | is pre-cooling, warehouses are third-party/production-area assets, and industrial refrigeration is factory process demand. Residual overlap and omitted retail/road/ice loads remain possible. | $ktCO_2$/yr of indirect emissions [18][20][21]. |
| Food-loss and refrigerant context | Applying the national loss indicator of about 30% [65] to the 14.4 Mt/yr priority perishable-production basket [73] gives an indicative 4.3 Mt/yr of losses. A broad 0.7-2.5 $tCO_2eq$/t product-footprint range [77][78] is retained only as a separate sensitivity. | Indicative food-loss emissions: approximately 3-11 $MtCO_2eq$/yr, reported separately from refrigeration energy. Direct refrigerant emissions remain unquantified because national charge, refrigerant-mix and leakage data are unavailable. |

The resulting national screening envelope is approximately 155-250 GWh/yr of operational refrigeration electricity, or about 1.2-1.9% of national electricity production. At the report's 0.274 $kgCO_2$/kWh electricity-consumption factor [20][21], this corresponds to approximately 43-69 $ktCO_2$/yr of indirect emissions. The range is not an observed central estimate: uncertainty is dominated by the end-use share of formal food and beverage manufacturing, followed by incomplete warehouse-volume data and connected time for reefers. Actual operational emissions may be higher where diesel generation is used or lower where dedicated renewable supply is present. The separate food-loss sensitivity remains approximately 3-11 $MtCO_2eq$/yr and is not added to the refrigeration footprint. Direct refrigerant emissions remain outside the quantified total because national data on installed charge, refrigerant mix and leakage rates are unavailable.

## Market and operational constraints

Cold-chain expansion is constrained by high capital costs, seasonal utilisation, fragmented supply, uncertain off-take, unreliable or costly energy and limited maintenance capacity. World Bank assessments describe these factors as recurring obstacles across domestic agricultural value chains [12][64]. Table 31 summarises their sector-level effects and the market responses currently observed.

*Table 31 – Kenya: food cold-chain market and operational constraints*

| Constraint | Effect on sector development | Observed market response or implication |
|---|---|---|
| High upfront cost and limited collateral | Smallholders, cooperatives and market operators have difficulty financing efficient equipment even where latent demand exists. | Leasing, pay-per-use, shared cold rooms and service-based models are emerging, but remain limited in scale. |
| Seasonal and uncertain utilisation | Low occupancy weakens cash flow and increases electricity use per tonne handled. | Multi-commodity aggregation and anchor customers are common features of the more viable operating models. |
| Fragmented supply and weak off-take | Insufficient aggregation can leave assets underused and disconnect cooling from market demand. | Cooperative aggregation, retailer links and processor contracts are more developed in formal dairy and export horticulture. |
| Unreliable or costly energy | Temperature excursions, product loss and diesel dependence raise operating costs. | High-efficiency equipment, thermal storage and solar-hybrid systems are increasingly visible in weak-grid and off-grid applications. |
| Limited operation and maintenance capacity | Poor controls, refrigerant leakage and long outages reduce reliability and service life. | Remote monitoring, supplier service contracts and local technician training are growing but remain uneven outside major urban centres. |
| Regulatory and refrigerant transition | Legacy equipment can be inefficient, difficult to service or dependent on high-GWP refrigerants. | MEPS, the NCAP and the Kigali phase-down are shifting the market toward more efficient and lower-GWP systems [14][16][17]. |

## Technology landscape

The technology mix varies with product temperature, throughput, energy access and local service capacity. Table 32 describes the main technology families already present or emerging in Kenya and their national relevance.

*Table 32 – Kenya: food cold-chain technology landscape*

| Technology family | Main applications | National relevance and limitations |
|---|---|---|
| Rapid pre-cooling and heat removal | Fresh horticulture at farms, aggregation centres and packhouses. | Well established in formal export chains but much less available in domestic first-mile systems; water, hygiene and throughput are key operating constraints. |
| Modular solar or hybrid cold rooms | Off-grid or weak-grid aggregation sites and markets. | Growing pilot and commercial activity; modularity and low grid dependence are advantages, while utilisation, maintenance and cost per tonne remain critical [64]. |
| Milk chilling systems | Dairy cooperatives, processors and collection centres. | The most clearly established domestic cold-chain application, concentrated in the formal 20% of the dairy market [64]. |
| Ice and chilled systems for fisheries | Landing sites, collection routes and fish markets. | High potential for loss reduction, but constrained by potable water, sanitation, corrosion, dispersed supply and transport conditions [65]. |
| Temperature-controlled transport | First-mile collection, urban distribution and export interfaces. | Availability is increasing but remains costly; road conditions, load consolidation and return utilisation affect economic performance. |
| Low-GWP refrigeration and digital controls | Stationary and transport refrigeration. | Policy direction favours lower-GWP refrigerants, leak reduction, temperature monitoring and improved servicing capacity [16][17]. |

## National snapshot

Table 33 consolidates the principal national indicators, structural constraints and areas of uncertainty in Kenya's food cold chain.

*Table 33 – Kenya: food cold-chain national summary*

| Dimension | Current national situation | Outlook and uncertainty |
|---|---|---|
| Infrastructure coverage | Cold-chain capacity is concentrated in formal dairy, export horticulture, food processing, large third-party warehouses and selected logistics nodes. Secondary reporting attributes 1,367 reefer plug points across Mombasa, Nairobi, Lamu and Naivasha to KPA [67]. | Domestic first-mile, wholesale and informal-market coverage remains low. No national asset register reconciles processor-owned, packhouse, retail and third-party capacity. |
| Estimated electricity use | A bounded national estimate covering pre-processing milk chilling, export pre-cooling, stationary warehousing, containerised reefers and industrial process refrigeration is approximately 155-250 GWh/yr. | The range is dominated by the uncertain refrigeration share of formal food and beverage manufacturing. Retail refrigeration, dedicated road-transport units and informal ice production remain outside the quantified boundary. |

| Dimension | Current national situation | Outlook and uncertainty |
|---|---|---|
| Greenhouse-gas emissions | Indirect emissions from the bounded electricity estimate are approximately 43-69 $ktCO_2$/yr. A separate food-loss sensitivity is approximately 3-11 $MtCO_2eq$/yr. | Actual energy emissions depend on the grid/diesel/renewable supply mix. Direct refrigerant leakage is unquantified; food-loss emissions are highly sensitive to commodity mix, loss stage and life-cycle boundary. |
| Market structure | Export and formal processing chains are comparatively organised; domestic systems remain fragmented and dominated by small producers, traders and open markets [12][64]. | Urbanisation, formal retail and processor demand are likely to expand temperature-controlled distribution, but affordability remains a constraint. |
| Technology and skills | Milk chillers, export packhouses and conventional cold rooms form the established base; modular solar systems, digital monitoring and lower-GWP equipment are expanding. | Maintenance capacity, spare-parts availability and technician skills remain uneven, especially outside major cities. |
| Data quality | The estimate combines official industrial electricity data [71], the Kenya RAC inventory [24], secondary Q1 2024 reefer activity and plug-point reporting attributed to KPA [67], Kenya market assessments [64][73], and published engineering benchmarks [68][69][72]. | No complete national register links equipment stock, conditioned volume, throughput, residence time, refrigerant charge and metered energy use. The results are therefore a transparent screening range rather than an inventory-grade total. |

# References


[1] World Bank, "GDP (current US$) – Kenya," World Development Indicators. [Online]. Available: https://data.worldbank.org/indicator/NY.GDP.MKTP.CD?locations=KE. [Accessed: Jul. 20, 2026].

[2] World Bank Group, "Climate Change Knowledge Portal: Cooling Degree Days, Kenya, CMIP6 SSP2-4.5 dataset," 2026. [Online]. Available: https://climateknowledgeportal.worldbank.org/netcdf-browser/?prefix=data/cmip6-x0.25/cdd65/ukesm1-0-ll-r1i1p1f2-ssp245/. [Accessed: May 4, 2026].

[3] World Bank, "GDP per capita (current US$) – Kenya," World Development Indicators. [Online]. Available: https://data.worldbank.org/indicator/NY.GDP.PCAP.CD?locations=KE. [Accessed: Jul. 20, 2026].

[4] Sustainable Energy for All, "Sustainable Cooling for All in Kenya: Meeting Cooling Needs While Accelerating a Just and Equitable Transition," Vienna, 2024. [Online]. Available: https://www.seforall.org/system/files/2024-11/SEforALL-Kenya-Cooling-Report-Final-webversion.pdf. [Accessed: Jul. 20, 2026].

[5] International Monetary Fund, "World Economic Outlook Database, April 2026," Washington, DC, 2026. [Online]. Available: https://www.imf.org/en/Publications/WEO/weo-database/2026/April. [Accessed: Jul. 20, 2026].

[6] World Bank, "Population, total – Kenya," World Development Indicators. [Online]. Available: https://data.worldbank.org/indicator/SP.POP.TOTL?locations=KE. [Accessed: Jul. 20, 2026].

[7] World Bank, "Population growth (annual %) – Kenya," World Development Indicators. [Online]. Available: https://data.worldbank.org/indicator/SP.POP.GROW?locations=KE. [Accessed: Jul. 20, 2026].

[8] Republic of Kenya, Ministry of Environment, Climate Change and Forestry, "Kenya's Third National Communication to the United Nations Framework Convention on Climate Change," Nairobi, 2024. [Online]. Available: https://unfccc.int/sites/default/files/resource/MoECCF%20Kenya%20National%20Communication.pdf. [Accessed: Jul. 20, 2026].

[9] World Bank, "Urban population (% of total population) – Kenya," World Development Indicators. [Online]. Available: https://data.worldbank.org/indicator/SP.URB.TOTL.IN.ZS?locations=KE. [Accessed: Jul. 20, 2026].

[10] World Bank, "Urban population growth (annual %) – Kenya," World Development Indicators. [Online]. Available: https://data.worldbank.org/indicator/SP.URB.GROW?locations=KE. [Accessed: Jul. 20, 2026].

[11] Kenya Institute for Public Policy Research and Analysis, "Kenya Economic Report 2025," Nairobi, 2025. [Online]. Available: https://kippra.or.ke/download/kenya-economic-report-2025/. [Accessed: Jul. 20, 2026].

[12] World Bank, "World Agro Logistics and Cold Chain Investment: COOL MOVE—An Integrated Solution Focusing on Cold Chain Investments to Reduce Food Loss in East and Southern Africa," Report No. AUS0003395, Washington, DC, 2023. [Online]. Available: https://documents.worldbank.org/en/publication/documents-reports/documentdetail/099053123202039183. [Accessed: Jul. 20, 2026].

[13] World Bank, "Access to electricity (% of population) – Kenya," World Development Indicators. [Online]. Available: https://data.worldbank.org/indicator/EG.ELC.ACCS.ZS?locations=KE. [Accessed: Jul. 20, 2026].

[14] Republic of Kenya, "The Energy (Appliances' Energy Performance and Labelling) Regulations, 2016," Legal Notice No. 125 of 2016, Kenya Law. [Online]. Available: https://new.kenyalaw.org/akn/ke/act/ln/2016/125/eng@2019-01-04. [Accessed: Jul. 20, 2026].

[15] CLASP, "KS 2463:2019 – Non-ducted Air Conditioners: Testing and Rating of Performance," Climate Policy Resource Center, 2019. [Online]. Available: https://cprc-clasp.ngo/policies/ks-24632019-non-ducted-air-conditioners-testing-and-rating-performance. [Accessed: May 14, 2026].

[16] Republic of Kenya, Ministry of Environment, Climate Change and Forestry, "National Cooling Action Plan for Kenya," Nairobi, May 2023. [Online]. Available: https://www.green-cooling-initiative.org/fileadmin/230607_NCAP-for-Kenya22high_1.pdf. [Accessed: Jul. 20, 2026].

[17] United Nations, "Kigali Amendment to the Montreal Protocol on Substances that Deplete the Ozone Layer," Treaty Collection, 2016. [Online]. Available: https://treaties.un.org/Pages/ViewDetails.aspx?src=IND&mtdsg_no=XXVII-2-f&chapter=27. [Accessed: Jul. 20, 2026].

[18] Energy and Petroleum Regulatory Authority, "Energy & Petroleum Statistics Report for the Financial Year Ended 30 June 2025," Nairobi, 2025. [Online]. Available: https://www.epra.go.ke/sites/default/files/2025-09/Statistics-Report-June-2025-Web.pdf. [Accessed: Jul. 20, 2026].

[19] Kenya Bureau of Standards, "Pre-Export Verification of Conformity to Standards Programme: PVoC Manual, Version 15," Nairobi, 2026. [Online]. Available: https://www.kebs.org/wp-content/uploads/2026/02/PVOC-MANUAL-VERSION-15.pdf. [Accessed: Jul. 17, 2026].

[20] International Financial Institutions Technical Working Group on Greenhouse Gas Accounting, "Harmonized IFI Default Grid Factors 2021, Version 3.2," Apr. 2022. [Online]. Available: https://unfccc.int/sites/default/files/resource/Harmonized_IFI_Default_Grid_Factors_2021_v3.2_0.xlsx. [Accessed: Jul. 20, 2026].

[21] International Financial Institutions Technical Working Group on Greenhouse Gas Accounting, "Methodology/Approach to Account Project Emissions Associated with Grid Electricity Consumption," IFI TWG-AHG-002, Version 01.0, Dec. 2020. [Online]. Available: https://unfccc.int/sites/default/files/resource/AHG-002_IFI_Approach_to_grid_electricity_consumption_v01_clean.pdf. [Accessed: Jul. 20, 2026].

[22] Kenya National Bureau of Statistics, "2019 Kenya Population and Housing Census, Volume I: Population by County and Sub-County," Nairobi, 2019. [Online]. Available: https://www.knbs.or.ke/wp-content/uploads/2023/09/2019-Kenya-population-and-Housing-Census-Volume-1-Population-By-County-And-Sub-County.pdf. [Accessed: Jul. 20, 2026].

[23] World Bank Group and Asian Development Bank, "Climate Risk Country Profile: Kenya," Washington, DC and Manila, 2021. [Online]. Available: https://climateknowledgeportal.worldbank.org/sites/default/files/2021-05/15724-WB_Kenya%20Country%20Profile-WEB.pdf. [Accessed: Jul. 20, 2026].

[24] Deutsche Gesellschaft für Internationale Zusammenarbeit (GIZ), "Greenhouse Gas Inventory for the Refrigeration and Air Conditioning Sector in Kenya," Green Cooling Initiative, Eschborn, 2022. [Online]. Available: https://www.green-cooling-initiative.org/fileadmin/user_upload/2022_GIZ_GCI_Greenhouse_Gas_Inventory_RAC_Kenya.pdf. [Accessed: Jul. 20, 2026].

[25] Center for International Earth Science Information Network, Columbia University, "Global 1-km Downscaled Population Base Year and Projection Grids Based on the Shared Socioeconomic Pathways, Revision 01, Version 1.01," NASA Socioeconomic Data and Applications Center, 2020. [Online]. Available: https://www.earthdata.nasa.gov/data/catalog/sedac-ciesin-sedac-pd-sspbsyr-1km-1.01. [Accessed: May 4, 2026].

[26] Kenya National Bureau of Statistics, "2019 Kenya Population and Housing Census, Volume II: Distribution of Population by Administrative Units," Nairobi, 2019. [Online]. Available: https://www.knbs.or.ke/wp-content/uploads/2023/09/2019-Kenya-population-and-Housing-Census-Volume-2-Distribution-of-Population-by-Administrative-Units.pdf. [Accessed: Jul. 20, 2026].

[27] F. Ng'eno Chelang'at and R. Lawrence, "Challenging the Western Framing of Sustainability: A Contextual Analysis of Four Architectural Projects in Kenya," Buildings, vol. 14, no. 8, art. 2383, 2024, doi: 10.3390/buildings14082383.

[28] A. A. Scott et al., "Temperature and Heat in Informal Settlements in Nairobi," PLOS ONE, vol. 12, no. 11, art. e0187300, 2017, doi: 10.1371/journal.pone.0187300.

[29] L. Mentaschi et al., "Global Long-Term Mapping of Surface Temperature Shows Intensified Intra-City Urban Heat Island Extremes," Global Environmental Change, vol. 72, art. 102441, 2022, doi: 10.1016/j.gloenvcha.2021.102441.

[30] J. Kimutai, P. Nying'uro, L. Harrington, W. Oghera, and F. Otto, "Identification of Local Heat Thresholds and Related Health Impacts: The Case of Nairobi, Mombasa and Kisumu Cities in Kenya," Red Cross Red Crescent Climate Centre, 2022. [Online]. Available: https://preparecenter.org/wp-content/uploads/2022/12/Kenya-Heat-Tresholds-Research-by-J.Kimutai-2022.pdf. [Accessed: Jul. 20, 2026].

[31] I. K. Rotich, H. Chepkirui, and P. K. Musyimi, "Renewable Energy Status and Uptake in Kenya," Energy Strategy Reviews, vol. 54, art. 101453, 2024, doi: 10.1016/j.esr.2024.101453.

[32] Republic of Kenya, "The Energy Act, 2006," Act No. 12 of 2006, Kenya Law, Nairobi, 2006.

[33] Republic of Kenya, "The Energy (Energy Management) Regulations, 2012," Legal Notice No. 102 of 2012, Kenya Law, Nairobi, 2012.

[34] Republic of Kenya, "The Energy Act, 2019," Act No. 1 of 2019, Kenya Law. [Online]. Available: https://new.kenyalaw.org/akn/ke/act/2019/1/eng@2022-12-31. [Accessed: Jul. 20, 2026].

[35] CLASP, "Kenya's New AC Standards Increase Efficiency Baseline While Reducing Harmful Refrigerants," 2020. [Online]. Available: https://www.clasp.ngo/updates/kenyas-new-ac-standards-increase-efficiency-baseline-while-reducing-harmful-refrigerants/. [Accessed: May 11, 2026].

[36] Kenya Revenue Authority, "Importing and Exporting: Import Duties, VAT, Import Declaration Fee and Railway Development Levy," Nairobi. [Online]. Available: https://www.kra.go.ke/business/companies-partnerships/companies-partnerships-pin-taxes/company-partnership-imports-exemptions. [Accessed: Jul. 20, 2026].

[37] Public Procurement Regulatory Authority, "Access to Government Procurement Opportunities (AGPO)," Nairobi. [Online]. Available: https://ppra.go.ke/agpo/. [Accessed: Jul. 20, 2026].

[38] East African Court of Justice, "East African Court of Justice Halts Implementation of Kenya–EU Economic Partnership Agreement," interim injunction in Application No. 7 of 2024 arising from Reference No. 10 of 2024, Arusha, Nov. 24, 2025. [Online]. Available: https://www.eacj.org/?news=east-african-court-of-justice-halts-implementation-of-kenya-eu-economic-partnership-agreement. [Accessed: Jul. 20, 2026].

[39] F. Scorgie et al., "'Mothers Get Really Exhausted!' The Lived Experience of Pregnancy in Extreme Heat: Qualitative Findings from Kilifi, Kenya," Social Science & Medicine, vol. 335, art. 116223, 2023, doi: 10.1016/j.socscimed.2023.116223.

[40] International Energy Agency, "Energy Efficiency for Affordability: Improving People's Lives through Delivery of a Sustainable, Modern Energy System in Kenya," Paris, 2023. [Online]. Available: https://www.iea.org/reports/energy-efficiency-for-affordability. [Accessed: Jul. 20, 2026].

[41] Republic of Kenya, Ministry of Health, "Kenya Health Facility Census Report, September 2023," Nairobi, 2023. [Online]. Available: https://www.health.go.ke/sites/default/files/2024-01/Kenya%20Health%20Facility%20Census%20Report%20September%202023.pdf. [Accessed: Jul. 20, 2026].

[42] Republic of Kenya, Ministry of Health, "Clinical Guidelines for Management and Referral of Common Conditions at Level 4 Primary Care Hospitals, Level 5 Secondary Hospitals and Level 6 Tertiary Hospitals," vol. 3, Nairobi, 2024. [Online]. Available: https://health.go.ke/sites/default/files/2025-04/Clinical%20Guidelines%20for%20Management%20Level%204%20Primary%20Care%20Hospitals%20Level%205%20Secondary%20Hospitals%20Level%206%20Tertiary%20Hospitals%20%E2%80%93%20National%20Hospitals.pdf. [Accessed: Jul. 20, 2026].

[43] Republic of Kenya, Ministry of Health, "Kenya Master Health Facility Registry: Public Facilities Database." [Online]. Available: https://kmhfr.health.go.ke/public/facilities. [Accessed: May 5, 2026].

[44] World Bank, "Hospital Beds (per 1,000 People) – Kenya," World Development Indicators. [Online]. Available: https://data.worldbank.org/indicator/SH.MED.BEDS.ZS?locations=KE. [Accessed: May 5, 2026].

[45] Ministero della Salute, "Posti letto per regione e disciplina, 2021," Portale dei Dati della Salute, Italy. [Online]. Available: https://www.dati.salute.gov.it/it/dataset/posti-letto-regione-e-disciplina-2021/. [Accessed: May 5, 2026].

[46] World Health Organization, "Good Storage and Distribution Practices for Medical Products," WHO Technical Report Series No. 1025, Annex 7, Geneva, 2020. [Online]. Available: https://www.who.int/publications/m/item/trs-1025-annex-7. [Accessed: Jul. 20, 2026].

[47] S. W. Lindsay and W. J. M. Martens, "Malaria in the African Highlands: Past, Present and Future," Bulletin of the World Health Organization, vol. 76, no. 1, pp. 33–45, 1998.

[48] M. Romanello et al., "The 2021 Report of the Lancet Countdown on Health and Climate Change: Code Red for a Healthy Future," The Lancet, vol. 398, no. 10311, pp. 1619–1662, 2021, doi: 10.1016/S0140-6736(21)01787-6.

[49] M. Lutukai et al., "Using Data to Keep Vaccines Cold in Kenya: Remote Temperature Monitoring with Data Review Teams for Vaccine Management," Global Health: Science and Practice, vol. 7, no. 4, pp. 585–597, 2019, doi: 10.9745/GHSP-D-19-00157.

[50] Republic of Kenya, Ministry of Health, Unit of Vaccines and Immunization Services, "Immunization Manual for Health Workers," Nairobi, 2024. [Online]. Available: https://knowledge.unicef.org/resource/immunization-manual-health-workers. [Accessed: Jul. 20, 2026].

[51] D. Dadi, V. Introna, A. Santolamazza, M. Salvio, C. Martini, T. Pastura, and F. Martini, "Private Hospital Energy Performance Benchmarking Using Energy Audit Data: An Italian Case Study," Energies, vol. 15, no. 3, art. 806, 2022, doi: 10.3390/en15030806.

[52] B. C. Singer, P. Mathew, S. Greenberg, W. Tschudi, and D. Sartor, "Hospital Energy Benchmarking Guidance—Version 1.0," Lawrence Berkeley National Laboratory, Berkeley, CA, 2009. [Online]. Available: https://eta-publications.lbl.gov/sites/default/files/hospital_energy_benchmarking_guildance_-_version_1.0.pdf. [Accessed: Jul. 20, 2026].

[53] World Health Organization, World Bank, International Renewable Energy Agency, and Sustainable Energy for All, "Energizing Health: Accelerating Electricity Access in Health-Care Facilities," Geneva, 2023, ISBN 978-92-4-006698-4. [Online]. Available: https://www.who.int/publications/i/item/9789240066984. [Accessed: Jul. 20, 2026].

[54] Republic of Kenya, Ministry of Education, "Basic Education Statistical Booklet 2020," Nairobi, 2021.

[55] World Bank, "School Enrollment, Primary (% Gross) – Kenya," World Development Indicators. [Online]. Available: https://data.worldbank.org/indicator/SE.PRM.ENRR?locations=KE. [Accessed: May 12, 2026].

[56] Humanitarian OpenStreetMap Team, "Education Facilities of Kenya: OpenStreetMap Export," Humanitarian Data Exchange, 2026. [Online]. Available: https://data.humdata.org/dataset/hotosm_ken_education_facilities. [Accessed: Jul. 17, 2026].

[57] World Bank and UNESCO Institute for Statistics, "Proportion of Primary Schools with Access to Electricity (%) – Kenya," Education Statistics Database. [Online]. Available: https://databank.worldbank.org/source/education-statistics-%5e-all-indicators. [Accessed: May 13, 2026].

[58] P. Wargocki, J. A. Porras-Salazar, and S. Contreras-Espinoza, "The Relationship between Classroom Temperature and Children's Performance in School," Building and Environment, vol. 157, pp. 197–204, 2019, doi: 10.1016/j.buildenv.2019.04.046.

[59] E. F. Amankwaa, B. M. Roberts, P. Mensah, and K. V. Gough, "Impact of Roofing Materials on School Temperatures in Tropical Africa," Buildings and Cities, vol. 6, no. 1, pp. 139–157, 2025, doi: 10.5334/bc.581.

[60] Commission for University Education, "Universities Data Report 2022–2023," Nairobi, 2023. [Online]. Available: https://www.cue.or.ke/index.php?Itemid=187&download=276:universities-data-report-2022-2023&id=18:universities-data-0-3&option=com_phocadownload&view=category. [Accessed: Jul. 17, 2026].

[61] International Energy Agency, "Kenya: Energy Profile." [Online]. Available: https://www.iea.org/countries/kenya. [Accessed: May 4, 2026].

[62] N. P. Mdlalose, M. Muvengei, P. Muiruri, and U. Mutwiwa, “Thermal Performance Analysis of Near-Infrared Reflection and Green-Roof Cooling Techniques on Buildings Made of Mild Steel,” Renewable Energy and Environmental Sustainability, vol. 8, art. 13, 2023, doi: 10.1051/rees/2023014.

[63] Republic of Kenya, “The National Building Code, 2024,” Legal Notice No. 47 of 2024, Kenya Law. [Online]. Available: https://new.kenyalaw.org/akn/ke/act/ln/2024/47/eng@2024-03-01. [Accessed: Jul. 20, 2026].

[64] World Bank, “World Agro Logistics and Cool Chain Investment: Technical Support to Kenya and Rwanda—Summary Report,” Washington, DC, 2023. [Online]. Available: https://documents.worldbank.org/en/publication/documents-reports/documentdetail/099062623131520681. [Accessed: Jul. 20, 2026].

[65] Republic of Kenya, Ministry of Agriculture and Livestock Development, “Kenya Postharvest Management Strategy for Food Loss and Waste Reduction 2024–2028,” Nairobi, 2024. [Online]. Available: https://www.kilimo.go.ke/wp-content/uploads/2024/10/KENYA-POST-HARVEST-MANAGEMENT-ON-FOOD-LOSS-AND-WASTE-REDUCTION-STRATEGY.pdf. [Accessed: Jul. 20, 2026].

[66] Kenya Ports Authority, “Inland Container Depots.” [Online]. Available: https://www.kpa.co.ke/Ports/InlandContainerDepots. [Accessed: Jul. 20, 2026].

[67] Federation of East African Freight Forwarders Associations, “Mombasa Port Fresh Produce Export Records Impressive Growth,” 2024; secondary reporting of operational figures attributed to the Kenya Ports Authority. [Online]. Available: https://magazine.feaffa.com/mombasa-port-fresh-produce-export-records-impressive-growth/. [Accessed: Jul. 20, 2026].

[68] J. A. Evans et al., “Specific Energy Consumption Values for Various Refrigerated Food Cold Stores,” Energy and Buildings, vol. 74, pp. 141–151, 2014, doi: 10.1016/j.enbuild.2013.11.075.

[69] W. B. Fitzgerald, O. J. A. Howitt, I. J. Smith, and A. Hume, “Energy Use of Integral Refrigerated Containers in Maritime Transportation,” Energy Policy, vol. 39, no. 4, pp. 1885–1896, 2011, doi: 10.1016/j.enpol.2010.12.015.

[70] World Resources Institute and World Business Council for Sustainable Development, “Connecting Food Loss and Waste to Greenhouse Gas Emissions: Guidance for Companies,” Food Loss and Waste Protocol, 2021. [Online]. Available: https://flwprotocol.org/wp-content/uploads/2021/10/ConnectingFLWGHG-Emissions_GuidanceForCompanies.pdf. [Accessed: Jul. 20, 2026].

[71] Kenya National Bureau of Statistics, “Census of Industrial Production and Construction Report 2018,” Nairobi, Dec. 2019, reference year 2017, Table 5.13. [Online]. Available: https://www.knbs.or.ke/wp-content/uploads/2023/09/Census-of-Industrial-Production-Report-2019.pdf. [Accessed: Jul. 20, 2026].

[72] U.S. Energy Information Administration, “2022 Manufacturing Energy Consumption Survey, Table 5.1: End Uses of Fuel Consumption by Manufacturing Industry,” Washington, DC, Aug. 2025. [Online]. Available: https://www.eia.gov/consumption/manufacturing/data/2022/xls/Table5_1.xlsx. [Accessed: Jul. 20, 2026].

[73] EEP Africa, “Cold Chain Storage Market Assessment,” Helsinki, 2023. [Online]. Available: https://eepafrica.org/documents/Sector-Briefs/cold-chain-storage-market-assessment-2023.pdf. [Accessed: Jul. 20, 2026].

[74] Cold Solutions Kenya Limited, “Background Information Document: Environmental Impact Assessment for the Tatu City Temperature-Controlled Storage Facility,” Apr. 2020. [Online]. Available: https://www.coldsolutionskenya.com/wp-content/uploads/2025/06/Cold-Solutions_EIA-BID-15.05.2020.pdf. [Accessed: Jul. 20, 2026].

[75] Cold Solutions Kenya, “Temperature-Controlled Storage Facilities,” operator-reported capacity of approximately 20,000 pallets across Tatu City and Mombasa. [Online]. Available: https://www.coldsolutionskenya.com/. [Accessed: Jul. 20, 2026].

[76] W. B. Tuszyński, E. A. A. Diakowska, and N. S. Hall, “Solar Energy in Small-Scale Milk Collection and Processing,” FAO Animal Production and Health Paper No. 39, Food and Agriculture Organization of the United Nations, Rome, 1983. [Online]. Available: https://www.fao.org/4/X6541E/X6541E02.htm. [Accessed: Jul. 20, 2026].

[77] J. Poore and T. Nemecek, “Reducing Food’s Environmental Impacts through Producers and Consumers,” Science, vol. 360, no. 6392, pp. 987-992, 2018, doi: 10.1126/science.aaq0216.

[78] Our World in Data, “Greenhouse Gas Emissions per Kilogram of Food Product,” dataset adapted from Poore and Nemecek (2018), 2019. [Online]. Available: https://ourworldindata.org/grapher/ghg-per-kg-poore. [Accessed: Jul. 20, 2026].