Ethiopia

EPIC Deploy: Ethiopia 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

Ethiopia's cooling landscape is shaped by rapid demographic growth, a pronounced altitude-driven climatic heterogeneity, an almost entirely hydro-based but capacity-constrained power system, and a regulatory framework that does not yet address cooling directly. 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 - Ethiopia: key cooling taxonomy data

Economics and Demographics		**Climatic conditions**	
GDP (2025, current)	approx. USD 126 B [1]	National avg. Cooling Degree Days (18 °C base)	2,169 °C·day/yr [2]
GDP per capita	approx. USD 933 [1]	Mean annual temperature (national)	22.6 °C [3]
GDP growth rate (recent)	approx. 8-9%/yr [4]	Temperature range across climatic zones	approx. 0-50 °C (alpine highlands to arid lowlands) [3]
Total population (2024)	approx. 132 M [5]	Warming trend since the 1960s	approx. +1.0 °C (approx. 0.25 °C/decade) [6]
Population growth rate	approx. 2.5%/yr [5]	Projected warming by mid-century	approx. +1.5 to +2 °C (scenario-dependent) [6]
Urban population share	approx. 23.7% (2024) [7]		
Urban growth rate	approx. 4.7%/yr [7]		
Growth-driving sectors	Agriculture, services, construction [4]		
Energy infrastructure		**Regulatory framework**	
National electrification rate	approx. 55% (2023) [8]	MEPS for cooling appliances	Not yet in force (planned) [9]
Urban electricity access	approx. 94% [10]	HCFC/R22 phase-out schedule	Article 5: -67.5% by 2025; -97.5% by 2030 [11]
Population without electricity	approx. 60 M (third-largest deficit in SSA) [10][12]	HFC phase-down (Kigali Amendment)	Ratified 5 July 2019; freeze 2024, -10% by 2029 [13][16]
Renewable share of generation	approx. 100% (hydro approx. 96%) [14]	National Cooling Action Plan	No adopted NCAP identified; status should be confirmed with the competent authority [41]
Grid reliability	Low (approx. 8.2 outages/month for firms) [17]	NDC emissions reduction target	70.3% below revised BAU by 2035 [15]
Residential electricity tariff	approx. USD 0.01-0.04/kWh by customer class [18][19][20]	Import charges	Duty 0-35%; VAT 15%; surtax 10% [21]
Total electricity production	20.5 TWh/yr (2023); hydro 96.5%, wind 3.3% [22]	Energy efficiency regulation	EEA mandate; Energy Efficiency Action Plan [23]
Grid emission factor	approx. 0.016 $kgCO_2eq/kWh$ [24]		

General Overview

Geography and climate

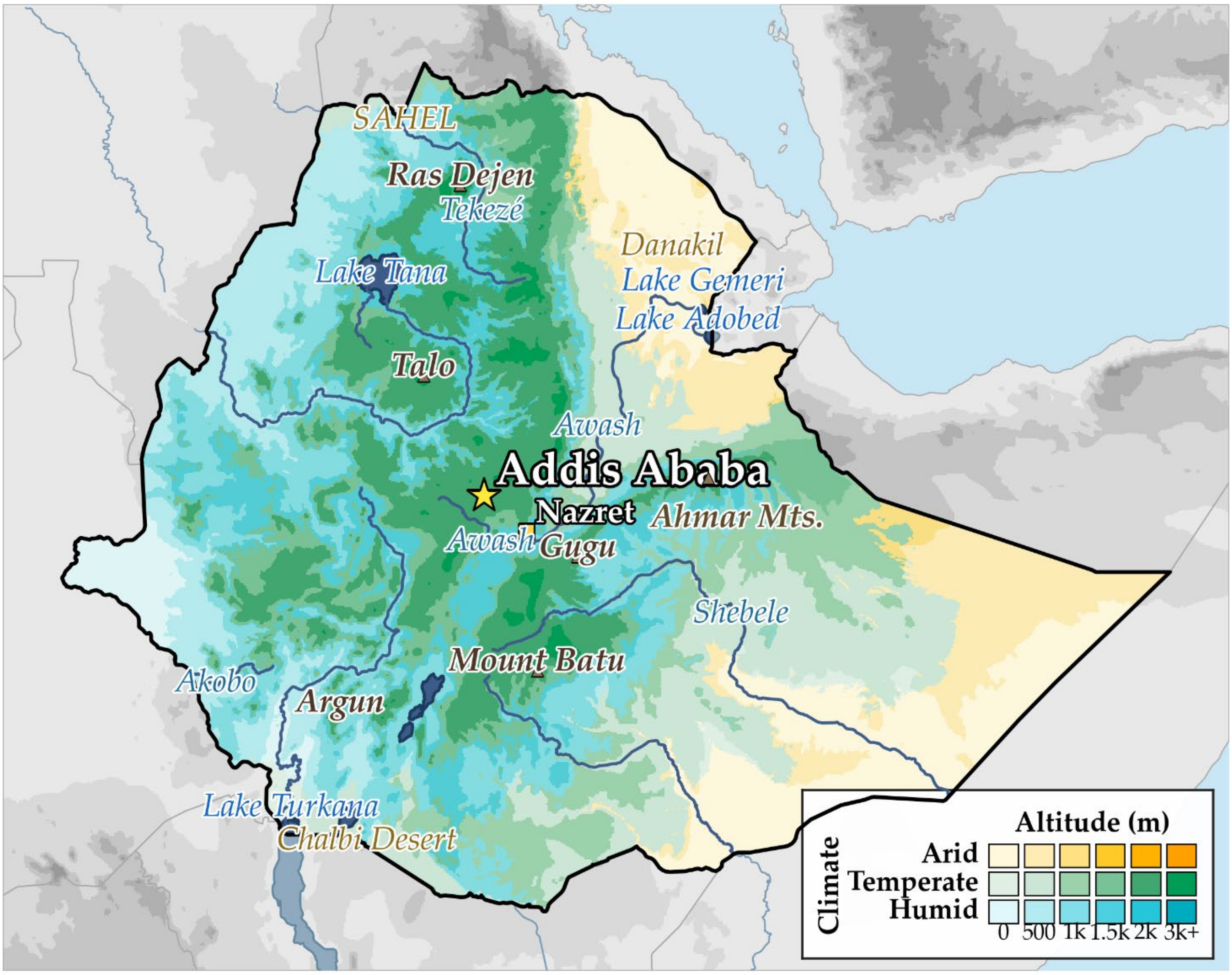
Ethiopia's climate is organized by altitude rather than latitude. The traditional classification distinguishes three main zones: the Dega (alpine highlands above approximately 2,600 m, with temperatures from around 0 to 16 °C), the Woina Dega (temperate midlands between roughly 1,500 and 2,500 m, from 16 to 30 °C) and the Kolla (hot arid and semi-arid lowlands below 1,500 m, where temperatures range from 27 up to 50 °C) [3][6]. The great majority of the population lives in the temperate highlands, while the hot lowlands of the east, south-east and west are sparsely settled [25]. Cooling demand therefore follows a distinctive pattern: it is structurally low across most of the settled highlands and acute in the lowland peripheries, where infrastructure and electricity access are weakest. The zonal breakdown in Figure 1, along with the data in Table 2, reflects this pattern and serves as a reference framework throughout the assessment.

The national cooling-degree-day figure is presented for cross-country comparison, but investment planning should be based on spatial exposure. In Ethiopia the decisive cooling geography is the overlap between the hot lowlands, weak electricity access, sparse health and education infrastructure, and the agricultural corridors. Because cooling exposure depends less on land area than on that spatial overlap, this assessment uses cooling-degree-day mapping together with facility and population distribution rather than simple agro-ecological area shares.

Table 2 - Ethiopia: climatic zone general data

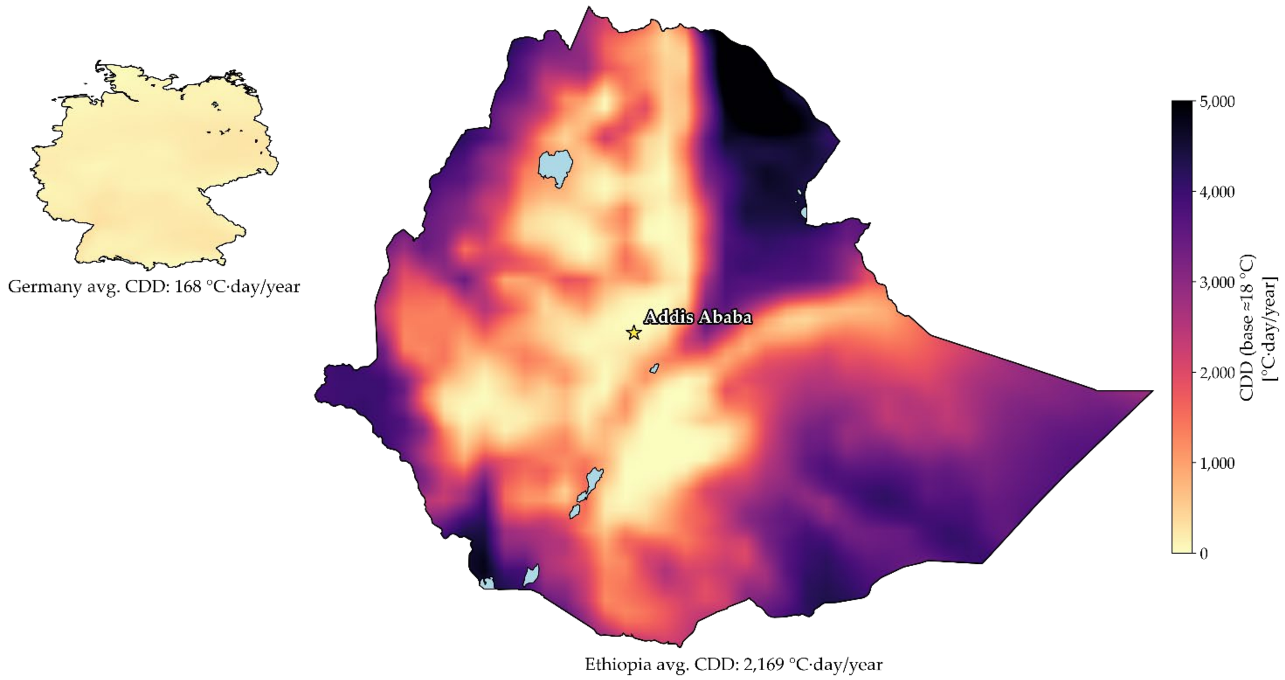
Zone	Altitude and temperature	Population	Key cooling relevance
Dega (alpine highlands)	above approx. 2,600 m; approx. 0-16 °C [3]	Smaller share; high-density farming areas [25]	Minimal active-cooling demand; heating is the dominant comfort need
Woina Dega (temperate midlands)	approx. 1,500-2,500 m; 16-30 °C [3]	Concentrates the large majority of the population (approx. 70-80%) and of urban economic activity, including Addis Ababa [25]	Low-to-moderate comfort cooling; refrigeration demand driven by services and food systems
Kolla (hot arid / semi-arid lowlands)	below approx. 1,500 m; 27-50 °C [3]	Sparsely settled; predominantly pastoralist (Afar, Somali, Gambela lowlands) [3][25]	Highest cooling demand; predominantly off-grid; weakest infrastructure

Figure 1 - Ethiopia: geography and climatic zones



Climate projections compound the structural challenge. Mean temperatures have risen by approximately 1.0 °C since the 1960s, at a rate of roughly 0.25 °C per decade, and further warming of approximately 1.5 to 2 °C is projected by mid-century under medium-to-high emission scenarios [6]. The national mean annual temperature is 22.6 °C, but the average conceals extremes that range from alpine frost to some of the hottest inhabited lowlands on the continent [3], so a single national Cooling Degree Days figure has limited descriptive value and the spatial distribution shown in Figure 2 is the more meaningful reference. The national average CDD value (18 °C base) is 2,169 [2]. Ethiopia is included among the countries with high-temperature regions in the global assessment of cooling-access risk, which identifies the arid lowlands as areas where lack of access to cooling puts vulnerable populations at risk [26].

Figure 2 - Ethiopia: cooling degree days 18 °C spatial distribution



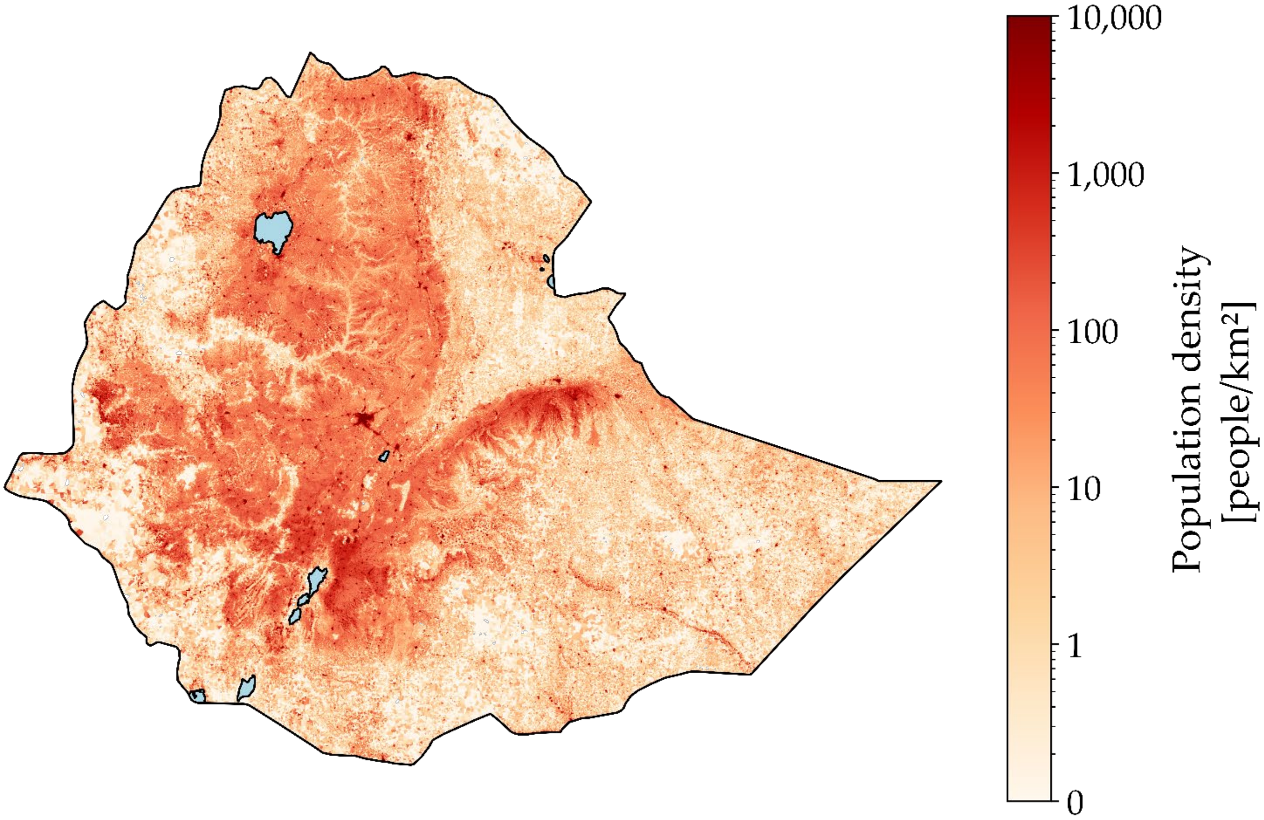
Population, Urbanisation and Vulnerability

Ethiopia is the second most populous country in Africa and one of the fastest-growing worldwide. Population is projected to rise from approximately 132 million in 2024 to about 153 million in 2030 and 225 million by 2050 [5]. Urbanisation is accelerating from a low base: the urban share is approximately 23.7% and growing at about 4.7% per year [7], with the urban population projected to rise from 24.5 million to 42.3 million by 2037 [27]. Addis Ababa hosts approximately 4% of the national population but generates around 20% of GDP [27]. Conflict and climate shocks add a further layer of vulnerability: the country counts approximately 3.4 million internally displaced persons and hosts around 1 million refugees [27]. Key indicators are reported in Table 3.

Table 3 - Ethiopia: general demographic data

Indicator	Value	Source
Total population (2024)	approx. 132 M	[5]
Population growth rate	approx. 2.5%/yr	[5]
Projected population by 2030 / 2050	approx. 153 M / 225 M	[5]
Urban population share (2024)	approx. 23.7%	[7]
Urban growth rate	approx. 4.7%/yr	[7]
Urban population by 2037	from 24.5 M to approx. 42.3 M	[27]
Addis Ababa share of population / GDP	approx. 4% / approx. 20%	[27]
Internally displaced persons	approx. 3.4 M	[27]

Figure 3 - Ethiopia: population density



Urban growth beyond the capacity of formal housing supply channels a large share of new residents into informal and substandard housing, which is thermally vulnerable through poor envelopes, minimal ventilation and scarce vegetation. This reinforces the need to treat passive cooling and urban heat mitigation as part of the cooling-access agenda, even where active cooling remains unaffordable. Limited electricity access in these areas further constrains adaptive capacity.

Building Stock and Thermal Exposure

The built environment is a growing determinant of heat risk in Ethiopian cities, and Addis Ababa provides the best-documented case. The city's built-up area expanded from 18.3% of the municipal territory in 1991 to 52.6% in 2021 [28]. Over roughly the same period, mean land surface temperature increased by around 8 °C (7.9 °C over 1985-2015 and 8.3 °C over 1991-2021 in two independent studies) [29][28], and the surface urban heat island intensity rose from 0.6 °C in 1992 to 2.3 °C in 2020 [30]. Densification with heat-retaining materials and the loss of vegetated surfaces concentrate thermal stress on low-income neighbourhoods, and the same pattern can be expected to extend to secondary cities as they grow.

Economy and Energy Poverty

Affordability is a structural constraint on cooling access. Ethiopia combines one of the largest economies in East Africa in absolute terms with one of the lowest income levels per capita: GDP is approximately USD 126 billion (current, 2025) [1] against a GDP per capita of around USD 933 [1]. Growth is strong, at about 8 to 9% in recent fiscal years, but poverty rose from 27% to 32% between 2016 and 2021, and climate change already costs an estimated 1 to 1.5% of GDP per year, projected to reach up to 5% by the 2040s [4]. A macroeconomic reform launched in July 2024, including the move to a floating exchange rate, is reshaping import conditions [4]. Selected indicators are reported in Table 4.

Table 4 - Ethiopia: main economic indicators

Indicator	Value	Source
GDP (2025, current)	approx. USD 126 B	[1]
GDP per capita	approx. USD 933	[1]
GDP growth (recent fiscal years)	approx. 8-9%/yr	[4]
Poverty rate (2016 to 2021)	from 27% to 32%	[4]
Climate-related economic cost	1-1.5% of GDP/yr, up to 5% by the 2040s	[4]
Post-harvest losses (horticulture / milk / meat)	30-50% / approx. 30% / approx. 40%	[31]
Cold chain market value (2024 to 2033)	USD 323 M to USD 917 M	[32]

With income levels of this order and roughly 60 million people without electricity access [10], the market for active cooling remains nascent outside the main cities. At the same time, post-harvest losses of 30 to 50% for horticulture [31] and a cold chain market projected to almost triple by 2033 [32] indicate that the economic case for cooling investment is substantial, particularly in agricultural value chains.

Electricity system

Ethiopia's electricity system pairs one of the cleanest generation mixes in the world with one of its largest access deficits. Generation is essentially 100% renewable and hydro-dominated (approximately 96% hydropower), for a total of 20,515 GWh in 2023 [22], and installed capacity has tripled since 2010 to about 6.1 GW, with the Grand Ethiopian Renaissance Dam (5.15 GW) and Koysha (2.16 GW) adding large increments and electricity already exported to neighbouring countries [33]. National electricity access, however, stands at approximately 55% (2023): urban access is around 94%, but roughly 60 million people remain without electricity, the third-largest access deficit in Sub-Saharan Africa [8][10][12]. Key system indicators are reported in Table 5.

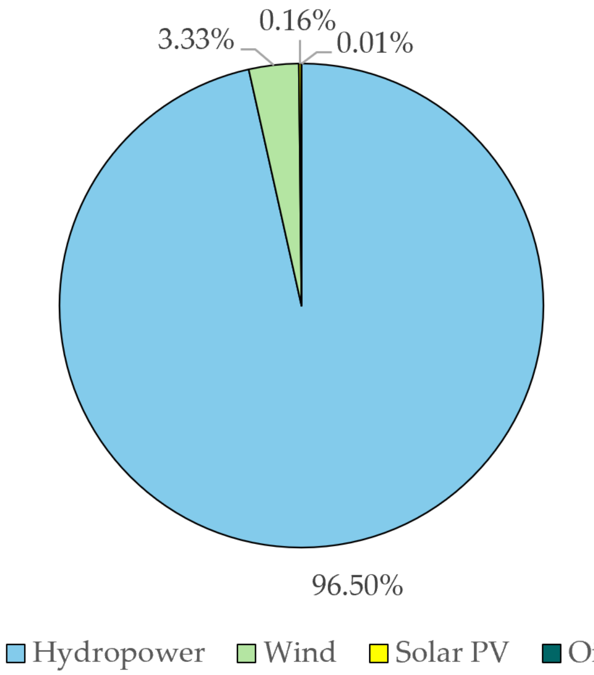
The composition of that output is unusually concentrated. Of the 20,515 GWh generated in 2023, hydropower supplied 19,796 GWh (96.5%), wind 684 GWh (3.3%) and solar PV 33 GWh (0.2%), with thermal generation reduced to a rounding error of 2 GWh. Generation has also risen steeply, from 14,526 GWh in 2018, an increase of about 41% in five years as new hydropower capacity has come online [22].

Table 5 - Ethiopia: electricity system key indicators

Indicator	Value	Source
National electrification rate (2023)	approx. 55.4%	[8]
Urban electricity access	approx. 94%	[10]
Population without electricity	approx. 60 M (third-largest deficit in SSA)	[10][12]
Renewable share of generation	approx. 100% (hydro approx. 96.5%)	[14]
Installed capacity (2024)	approx. 6.1 GW (tripled since 2010)	[33]
Total production (2023)	20.5 TWh/yr	[22]
Grid outages, firms (Enterprise Surveys)	approx. 8.2/month, approx. 5.8 h/event	[17]
Utility-reported interruptions	approx. 39/month, approx. 21 h/month in total	[34]

Indicator	Value	Source
Urban households experiencing outages	approx. 60% face 4-14 outages/week	[35]
Residential electricity tariff	approx. USD 0.01-0.04/kWh by customer class	[18][19]
Grid emission factor	approx. 0.016 $kgCO_2eq/kWh$	[24]

Figure 4 - Ethiopia: electricity production share



Reliability statistics differ by source but agree on the substance: World Bank Enterprise Surveys report approximately 8.2 outages per month for firms, of about 5.8 hours each [17], utility-level monitoring cited in governance analyses indicates around 39 interruptions per month totalling roughly 21 hours [34], and about 60% of urban households experience between 4 and 14 outages per week, with documented food spoilage and appliance damage [35]. For cooling, three implications follow. First, any continuously refrigerated load needs backup or storage by design. Second, the very low tariff, around USD 0.01/kWh [18], keeps operating costs marginal but also weakens the commercial incentive for energy-efficient equipment. Third, with a grid emission factor of approximately 0.016 $kgCO_2eq/kWh$ [24], the climate impact of cooling in Ethiopia is dominated by refrigerant leakage and, where diesel backup substitutes for the grid, by backup generation rather than by grid electricity itself. Hydropower dependence also introduces hydrological risk, as drought years constrain generation precisely when cooling demand peaks; the planned expansion toward 13.5 GW of hydropower by 2040, complemented by solar and geothermal capacity, is intended to mitigate this concentration [36].

Regulatory Framework

Key legislation

Ethiopia's energy regulatory framework is developing rapidly but does not yet address cooling as a distinct policy object. The foundations are the Energy Proclamation No. 810/2013, which established the Ethiopian Energy Authority and opened the sector to private investment [37], implemented through Council of Ministers regulations [38][39]. Climate policy is anchored in the Climate Resilient Green Economy strategy and Ethiopia's NDC 3.0, submitted in September 2025, which targets a 70.3% reduction in greenhouse-gas emissions below the revised business-as-usual pathway by 2035 [15]. No formally adopted National Cooling Action Plan was identified through the sources reviewed; the 2025 cooling roadmap identifies its development as a policy direction, and the current status should be confirmed with the competent authority [41]. The key instruments are summarized in Table 6.

Table 6 - Ethiopia: list of administrative key provisions

Instrument	Year	Key provision
Energy Proclamation No. 810/2013	2013	Foundation of energy regulation; establishment of the EEA; sector opened to private investment [37]
Council of Ministers Regulation No. 308/2014	2014	Organisation of the Ethiopian Energy Authority [39]
Energy Regulation No. 447/2019	2019	Implementing regulation under the Energy Proclamation [38]
CRGE Strategy	2011	Climate Resilient Green Economy: green-growth framework guiding climate policy [15]
NDC 3.0	2025	70.3% GHG reduction below revised BAU by 2035 [15]
Energy Efficiency Action Plan (EEA / RMI)	2023	Efficiency roadmap; savings potential approx. 14% of end-use electricity demand by 2030 [23]
National Cooling Action Plan	Status	No adopted plan identified through the sources reviewed; confirm current status with the competent authority [41]

In practice the framework is younger and thinner than the demand it will need to govern, and the absence of cooling-specific instruments means that the standards embedded in donor programmes and public procurement currently function as the de facto cooling policy.

MEPS in force for cooling appliances

The absence of appliance MEPS is a quantified, not merely a formal, gap. The UNEP United for Efficiency country savings assessment models residential refrigerators, commercial refrigeration and room air conditioners for Ethiopia and finds that, without regulation, national electricity consumption would grow about 80% by 2040. Introducing MEPS at the minimum-ambition level would cut national electricity use by roughly 2.4 TWh per year by 2040, equivalent to about 14% of current national consumption and to the output of a 500 MW power plant, and save around USD 87 million a year on electricity bills. Room air conditioners alone account for 2.7% to 3.6% of that saving, and raising the set-point from 22 °C saves a further 6% to 10% per degree up to 27 °C [20].

The procurement implication is direct. Until national MEPS for cooling appliances are adopted, donor-funded and public procurement should act as the effective market standard, by requiring high-efficiency equipment, low-GWP refrigerants, leak-tight installation, demonstrated serviceability and end-of-life refrigerant recovery provisions in every tender.

No minimum energy performance standards are currently in force for air conditioners or refrigerating appliances. MEPS have so far been established only for electric injera mitad stoves (mandatory from 2025) and for electric motors (ES 6892:2021, minimum IE2) [39][9][40]. MEPS for refrigerators and air conditioners are under consideration, and the analytical basis for their introduction has been prepared through the U4E Country Savings Assessment, which models the savings achievable under minimum and high-ambition MEPS scenarios for residential refrigerators, commercial refrigeration and air conditioners [20]. The current status is summarised in Table 7.

Table 7 - Ethiopia: MEPS status for cooling appliances

Product	Status	Reference
Room air conditioners	No MEPS in force; introduction under consideration	[9][20]
Refrigerating appliances	No MEPS in force; introduction planned / considered	[9][20]

Product	Status	Reference
Electric injera mitad stoves	MEPS in force (two standards; mandatory from 2025)	[39]
Electric motors	ES 6892:2021 in force (minimum IE2, 0.75-375 kW)	[40]

For project developers this has a direct consequence: equipment specifications cannot rely on national MEPS as a quality floor. Procurement should reference international benchmarks, such as the U4E model regulation guidelines, and set efficiency and refrigerant requirements contractually [20].

Refrigerant transition timeline

Implementation has moved beyond ratification. The HCFC Phase-out Management Plan reached Stage II, approved in December 2021, and Ethiopia drafted a National Ozone Depleting Substance and Hydrofluorocarbons Management Strategy in the same year [41]. The UNEP/UNIDO Kigali HFC Implementation Plan states that the licensing and quota system was extended to HFCs in 2024 and that draft regulatory revisions include HFC phase-down provisions, a proposed ban on imports of new and used HCFC-based equipment from 1 January 2026, and a proposed ban on virgin HCFC refrigerants from 2030 [16]. Because the cited document describes draft revisions submitted for approval, their current legal status and implementation dates should be verified with the National Ozone Unit before procurement. The refrigerant specified today nevertheless remains material to the equipment's long-term serviceability.

Ethiopia is a Party to the Montreal Protocol, classified as a low-volume HCFC-consuming country, and ratified the Kigali Amendment on 5 July 2019 [13][42]. HCFC phase-out follows the standard Article 5 schedule under the HCFC Phase-out Management Plan approved in 2012: consumption freeze in 2013, a 35% reduction by 2020, 67.5% by 2025 and 97.5% by 2030, with a service tail allowed to 2040 [11]. For procurement the relevant point is not the historical HCFC baseline but the phase-out trajectory itself. Under the Kigali Amendment, HFC consumption freezes in 2024 with a first 10% reduction step in 2029 for Article 5 Group 1 countries [13]. Technology preferences expressed by African Article 5 countries favour natural and low-GWP refrigerants such as R290 and ammonia over high-GWP HFCs [43]. Transition milestones are set out in Table 8.

Table 8 - Ethiopia: refrigerant transition targets

Milestone	Target
HCFC/R22 consumption freeze	2013 (Article 5 baseline schedule) [11]
HCFC reduction 35% / 67.5% / 97.5%	2020 / 2025 / 2030, service tail to 2040 [11]
Kigali Amendment ratification	5 July 2019 [13]
HFC freeze / first reduction (Article 5 Group 1)	2024 / minus 10% by 2029 [13]
Preferred direction (new equipment)	Natural and low-GWP refrigerants (R290, NH_3, CO_2); R600a for medical refrigerators [43][44]

Key institutions

Regulatory oversight relevant to cooling is distributed across several authorities, whose roles are summarised in Table 9. Given that conformity, customs and refrigerant requirements apply before or at importation, developers should engage the relevant authorities at an early stage of project preparation.

Table 9 - Ethiopia: cooling key authorities

Authority	Role for cooling
Ministry of Water and Energy	Energy policy; CRGE energy-sector implementation [39]
Ethiopian Energy Authority (EEA)	Energy regulation and licensing; energy efficiency and MEPS development [37][9]

Authority	Role for cooling
Ethiopian Electric Power (EEP) / Ethiopian Electric Utility (EEU)	Generation and transmission / distribution and retail supply [38]
Environmental Protection Authority / National Ozone Unit	Montreal Protocol and Kigali implementation; ODS and HFC licensing [42]
Institute of Ethiopian Standards	National standards development (e.g. ES 6892:2021) [40]
Ethiopian Customs Commission	Import duties, taxes and clearance [21]
Ethiopian Investment Commission	Investment licensing and incentives [45]

Market entry in Ethiopia

Market entry for cooling equipment requires attention to conformity, customs, foreign-exchange and refrigerant requirements. The principal documentation and conformity steps are described in the public Ethiopia Country Commercial Guide, but product scope and implementation details should still be verified with the competent authorities before budgeting [21].

- Standards and conformity: verify with the Institute of Ethiopian Standards whether the product category falls under a compulsory Ethiopian standard. Regulated goods may require pre-export verification and a Certificate of Conformity before shipment; the applicable product scope and route should be confirmed with the competent authority and its appointed conformity-assessment bodies [21].
- Customs duties and taxes: budget for customs duty (0 to 35% depending on HS code), excise tax where applicable, VAT at 15%, surtax at 10% and a 3% withholding tax on imports [21].
- Foreign exchange: the July 2024 macroeconomic reform introduced a floating exchange rate; foreign-currency availability has historically constrained imports and should be factored into procurement timelines [4].
- Refrigerant notification and licensing: import licensing and quota controls apply to ozone-depleting substances and have been extended to HFCs; specify refrigerant type and charge in all documentation and do not specify R22 for new installations [11][16]. Detailed procedures should be verified at procurement stage with the National Ozone Unit because they depend on refrigerant type and charge.
- Incentives and exemptions: investment incentives are administered by the Ethiopian Investment Commission; duty treatment of solar and efficient-cooling equipment varies by classification [45]. Duty exemptions for renewable-energy and efficient-cooling equipment should be verified case by case with the Ethiopian Investment Commission and the Customs Commission, since treatment follows the applicable investment and customs classification.

Because conformity requirements, refrigerant licensing and fiscal treatment depend on product category, refrigerant type and HS classification, these items are procurement due-diligence steps rather than gaps in the national framework: they should be verified during procurement with the Institute of Ethiopian Standards, the National Ozone Unit, the Ethiopian Customs Commission and the Ethiopian Investment Commission.

Working assumptions for import charges are provided in Table 10 and should be verified with the relevant authority before final budgeting.

Table 10 - Ethiopia: import charges applicable

Charge	Working assumption
Customs duty	0-35% depending on HS code; confirm by sub-heading with the Ethiopian Customs Commission [21]
Excise tax	Applicable to selected goods; variable by product [21]
VAT	15% [21]

Charge	Working assumption
Surtax	10% on most imports [21]
Withholding tax	3% on imports (creditable against income tax) [21]
Inland logistics	Djibouti corridor costs (port handling, rail or road haul, dry-port charges, clearing) to be budgeted separately
Exemptions	No general exemption should be assumed at budgeting stage; any preferential treatment should be verified case by case under the applicable investment and customs classification.

Behavioural Context

Demand for cooling in Ethiopia is shaped by factors beyond thermal need alone. Survey evidence on urban households shows that around 65% of respondents struggle to identify energy-efficient appliances, partly because specifications are not available in local languages; only about 34% report using efficient appliances, and access to credit, product availability and intra-household decision-making are significant determinants of adoption [46]. Women face disproportionate exposure to heat-related risk, through domestic work in poorly ventilated housing and through documented health impacts during pregnancy, particularly in informal settlements exposed to urban heat [47]. As temperatures rise and incomes grow, cooling is shifting from a niche, institutionally driven purchase toward a mainstream aspiration, while the market remains dominated by low-efficiency imported equipment in the absence of MEPS [9][46].

Together, the geographic, demographic, economic and regulatory factors outlined in this section define the structural conditions within which cooling demand in Ethiopia operates. Altitude-driven climate, rapid urbanisation from a low base, an almost fully renewable but unreliable and under-extended grid, and the absence of cooling-specific regulation shape both the nature of cooling need and the boundaries of viable intervention. The sectoral analysis in the following sections builds on this baseline to assess demand, technology options and investment potential across the cooling dimensions identified in Table 1.

Tertiary-Sector Cooling

The sectoral estimates that follow are intended as screening-level assessments for investment prioritisation. Where Ethiopia-specific inventories are available they are used directly. Where measured operating data are not published, the assessment combines national facility data with engineering benchmarks and explicitly stated assumptions. The results should therefore be read as order-of-magnitude estimates suitable for comparing sectors, identifying the dominant emission drivers and defining procurement priorities, rather than as metered consumption inventories.

Healthcare

System infrastructure and facility inventory

Ethiopia operates a three-tier public health system. The Federal Ministry of Health (FMOH) sets policy and oversees national referral facilities, Regional Health Bureaus manage service delivery, and woreda (district) health offices run the primary level [48]. The basic unit is the Primary Health Care Unit, which in rural areas pairs five health posts with one health center; above it the Ethiopian Hospital Services Transformation Guidelines define three hospital tiers, the Primary Hospital (catchment 60,000-100,000), the General Hospital (1-1.5 million) and the Comprehensive Specialized Hospital (3.5-5 million) [49]. The Ethiopian estate is strongly weighted toward dispersed primary care and adopts a clear three-grade hospital hierarchy, which this chapter uses as the classification backbone.

Hospitals are recorded in the national health facility registry [50], which lists 602 operational hospitals: 384 Primary, 185 General and 33 Comprehensive Specialized. The facility-type breakdown is set out in Table 11.

Bed capacity is taken from the national facility registry, using reported inpatient beds where available and a tier-average imputation where a count is missing, as detailed in the methodology below. The EHSTG standards [49] are used only to define the functional tier, not to set capacity. Basic units without significant inpatient capacity (health posts and health centers) are excluded from the assessment, as these facilities carry minimal active-cooling loads.

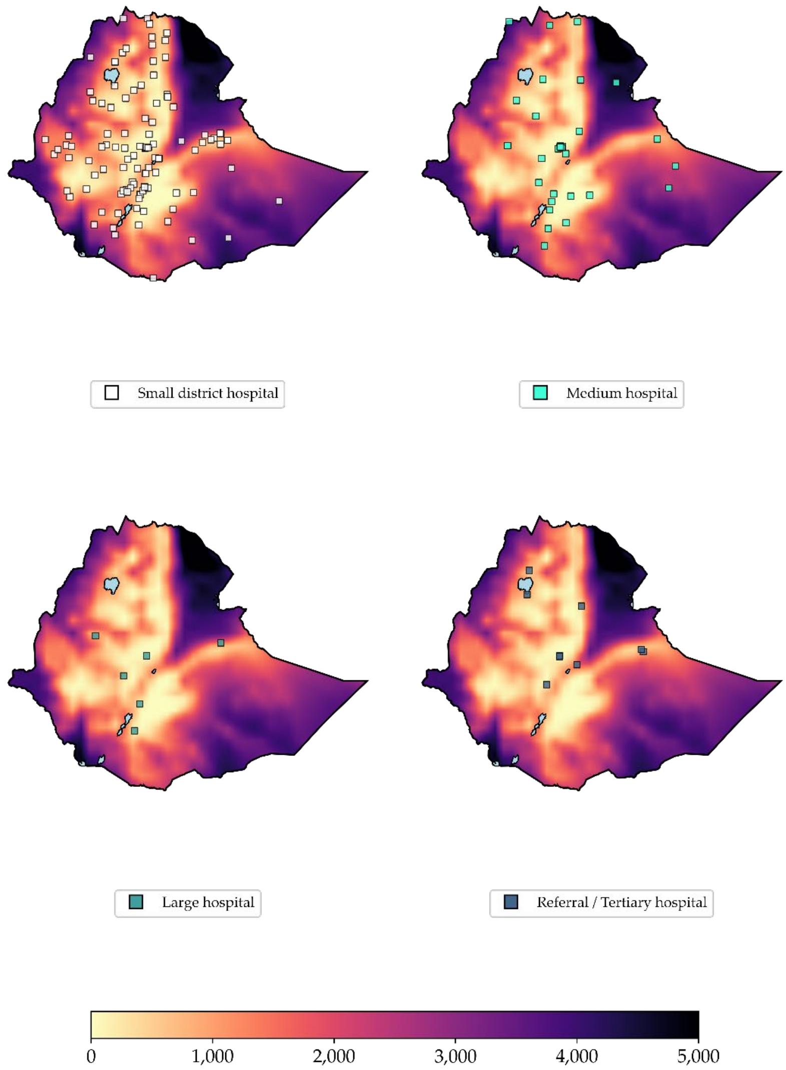
Table 11 – Ethiopia: healthcare facilities classification (elaboration on the national hospital registry [50] and EHSTG standards [49])

Healthcare Facility Type	Description	Facilities	Average beds/facility	Total capacity
Primary Hospital	First-level hospital; catchment 60,000-100,000	384	42	16,055
General Hospital	Second-level hospital; catchment 1-1.5 m	185	106	19,536
Comprehensive Specialized Hospital	Tertiary referral/teaching; catchment 3.5-5 m The EHSTG design standards define the functional role of each hospital tier. For the energy model, however, bed capacity is estimated from the national facility registry: reported inpatient beds are used where available, and tier-specific observed averages are applied to the facilities that do not report a bed count [50].	33	421	13,898

Latest national provision records stand at around 3.2 hospital beds per 10,000 inhabitants, meaning 0.32 per 1,000 [51], among the lowest in the world, against a global average of about 3.3 [52]. The registry-based operational hospital inventory used in this assessment implies a comparable order of magnitude (about 0.36-0.37 per 1,000), slightly above the official figure as it reflects reported and imputed operational capacity and continued network expansion since the last published value. The Ethiopian Public Health Institute sets minimum density norms per 100,000 inhabitants (20 health posts, 4 health centers, 1 primary hospital, 0.07 general and 0.02 referral hospitals) and assesses coverage within 5, 10 and beyond 10 km [53]. As Table 11 shows, the distribution is strongly skewed toward the first tier: the 384 Primary Hospitals are 64% of hospitals but under 40% of beds, while the 33 Comprehensive Specialized Hospitals concentrate specialised and intensive-care capacity. For cooling, this implies that basic-comfort and vaccine-storage needs are dispersed across many small facilities, whereas clinical-grade air treatment and chilled-water cooling are concentrated in the few largest hospitals.

The geographic distribution of facilities relative to thermal stress is shown in Figure 5. The size classes shown on the map (small, medium, large and referral) correspond to the report's hospital tiers as follows: small to Primary Hospitals, medium and large to General Hospitals, and referral to Comprehensive Specialized Hospitals. The areas where cooling demand is most acute, the arid lowlands of Afar, Somali and Gambela, are precisely those where hospital infrastructure is thinnest and most often off-grid, and where much of the new construction will need to take place. For any new facility in these zones, cooling cannot be treated as an optional specification.

Figure 5 – Ethiopia hospital facilities location vs cooling degree days 18°C distribution



Hospital bed distribution range across regions is wide: Harari records 14.3 beds per 10,000, Addis Ababa 10.6 and Dire Dawa 9.0, while Somali and South West Ethiopia record 2.0, Afar 2.4 and Oromia 2.6. The hot lowland regions are therefore the least provisioned, and they also report the lowest bed occupancy, 30% in Gambella and 32% in Afar against a national average of 67%, indicating that physical access and service readiness, not bed numbers alone, constrain utilization [51].

The cooling deficit and clinical consequences

In healthcare, cooling is an operational enabler rather than a matter of comfort, and its functions fall into three domains summarised in Table 12. The leading priority is the vaccine cold chain: the Health Facility Solar Electrification (HFSE) initiative, launched in October 2024 by the Ministry of Health together with Gavi, UNICEF and WHO, prioritises about 300 facilities distant from the grid, with roughly 6.7 million people in their catchment areas and a budget of about USD 35 million, pairing photovoltaic systems with cold-chain equipment through the CCEOP mechanism [54]. Across sub-Saharan Africa only about 34% of hospitals have reliable electricity [55].

The HFSE programme is therefore not simply an electrification intervention: it is the clearest example of integrated cooling-access infrastructure in Ethiopia, combining photovoltaic supply, vaccine refrigeration and service resilience in off-grid health facilities.

Clinical evidence from Ethiopia documents both cold-chain weaknesses in resource-limited settings, gaps associated with vaccine-preventable-disease outbreaks in the Tigray region [56], and the positive effect of solar direct-drive refrigeration on the quality and equity of immunisation services [57]. On thermal comfort and maternal-newborn health, a review of heat impacts in Africa cites Ethiopian studies indicating that in-utero exposure to high temperatures affects health across the life course [47], while an international meta-analysis finds that heat exposure raises the risk of preterm birth and stillbirth [58]. The same warming is expected to extend the malaria range into higher-altitude areas, adding to inpatient load.

Measured evidence from Ethiopian facilities makes the thermal burden concrete. A field study of public health facilities in Adama recorded indoor temperatures with windows closed of 29.5 °C to 34 °C in the afternoon across laboratories, wards and delivery and labour rooms, against outdoor temperatures of 24 °C to 31 °C, with window-to-floor ratios between 0.14 and 0.27. Opening windows lowered indoor temperature by 2 °C to 4 °C, showing that cross-ventilation and orientation remain effective and low-cost levers where active cooling is absent, but also that peak conditions in delivery and labour rooms sit well above clinical comfort thresholds [59]. Clinical preparedness lags the exposure: in a national survey of emergency nurses, 74% were dissatisfied with their own knowledge and skills for managing heat illness [60].

Table 12 – Ethiopia: healthcare cooling applications

Domain	Impact	Evidence / response
Vaccine cold chain (2 – 8 °C)	Unreliable electricity and a high share of off-grid facilities place vaccine potency at chronic risk; only ~34% of SSA hospitals have reliable power. [55]	HFSE: ~300 facilities prioritised, PV + cold-chain equipment; Solar Direct Drive selected for off-grid resilience; ~6.7 m people served. [54][57]
Medical storage & labs	Pharmaceuticals, blood products and diagnostic reagents require uninterrupted 24h climate control; a refrigeration failure interrupts pharmacy, laboratory and transfusion services.	Indispensable at facility level given the absence of centralized storage.
Clinical thermal comfort	Heat worsens maternal and neonatal outcomes; in the lowlands delivery rooms can exceed comfort thresholds. Expanding malaria range into the highlands raises inpatient load. [47][58]	Neonates, the elderly and peripartum women are most affected; Ethiopian in-utero heat studies cited in [47].

In Ethiopia the dominant constraint is the absence of reliable electricity at a large share of facilities. National access stands at about 55% [8], so the priority is less the replacement of LPG than solar electrification paired with cold-chain equipment, which is precisely the design of the HFSE programme. At national level the Health Sector Medium-Term Development and Investment Plan reports that 77% of health centers and hospitals have access to electricity, with a target of 85%, alongside 76% for water and 62% for basic sanitation. Only 1% of 764 assessed facilities met all seven basic amenity tracer items [61].

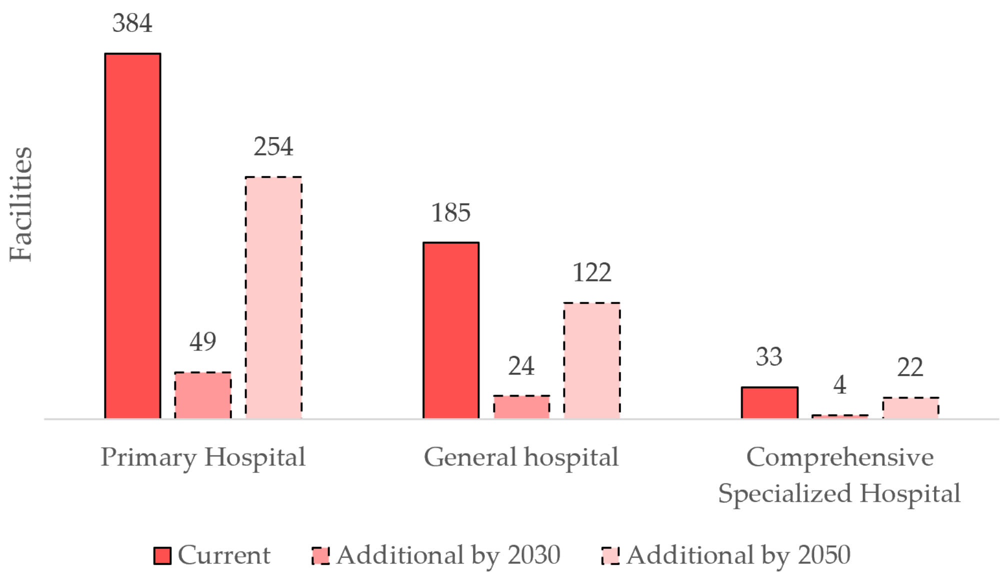
The vulnerability is documented inside the vaccine cold chain itself. Ethiopia distributes vaccines through five supply-chain levels, from the central store through regional and zonal stores and woreda distribution points to service delivery points. Peer-reviewed evidence from public health institutions in East Gojam found that only 76.7% of facilities had a functional refrigerator, 35% had a functional generator for back-up service and 46.6% had access to transport for vaccine transfer during refrigerator or power failure; temperature recording and cold-chain management practices were also incomplete [62]. Back-up power, equipment functionality and operating practice therefore remain binding constraints on vaccine integrity.

Infrastructure demand projections

Projections hold two current ratios constant: beds per 1,000 inhabitants and the distribution of capacity across the three hospital tiers. They therefore represent a demographic floor, not a development target. The population is projected to rise from about 135.5 million in 2025 to 152.9 million in 2030 and 225.0 million in 2050 [5]. Even holding the current and already inadequate provision of about 0.36 beds per 1,000 constant, population growth alone creates a substantial requirement for additional bed capacity. Figure 6 expresses that requirement as facility equivalents at the current average size of each tier.

On this basis Ethiopia would need about 6,300 additional beds by 2030 and about 32,600 by 2050. Holding the facility-type mix and current average size constant, this corresponds to roughly 254 Primary-Hospital equivalents, 122 General-Hospital equivalents and 22 Comprehensive-Specialized-Hospital equivalents by 2050, with about 49, 24 and 4 equivalents respectively by 2030. These values do not necessarily imply the construction of that number of stand-alone hospitals: capacity may be delivered through extensions, replacement buildings or new facilities. They show only the additional capacity required to prevent bed availability from falling further as the population grows, not the investment required to close Ethiopia's hospital-capacity gap. Closing that gap would require substantially more capacity. Each increment embeds a cooling load, and the efficiency and refrigerant standards adopted at design stage will determine sector energy use and emissions for decades.

Figure 6 – Ethiopia: current hospital stock and additional facility equivalents by type



Current market conditions and technology

An Ethiopia-specific equipment inventory is not available. The screening baseline therefore assumes that smaller and medium facilities are mainly served by direct-expansion split or VRF equipment and that centralized chilled-water systems are concentrated in larger referral hospitals; these are modelling assumptions rather than measured national market shares. Country-level figures for the installed medical-refrigerator stock are not separately published and are available only through multi-country Gavi aggregates (over 66,000 fridges installed worldwide through CCEOP, about 60% solar-powered) [44]. Key indicators and modelling directions are summarised in Table 13.

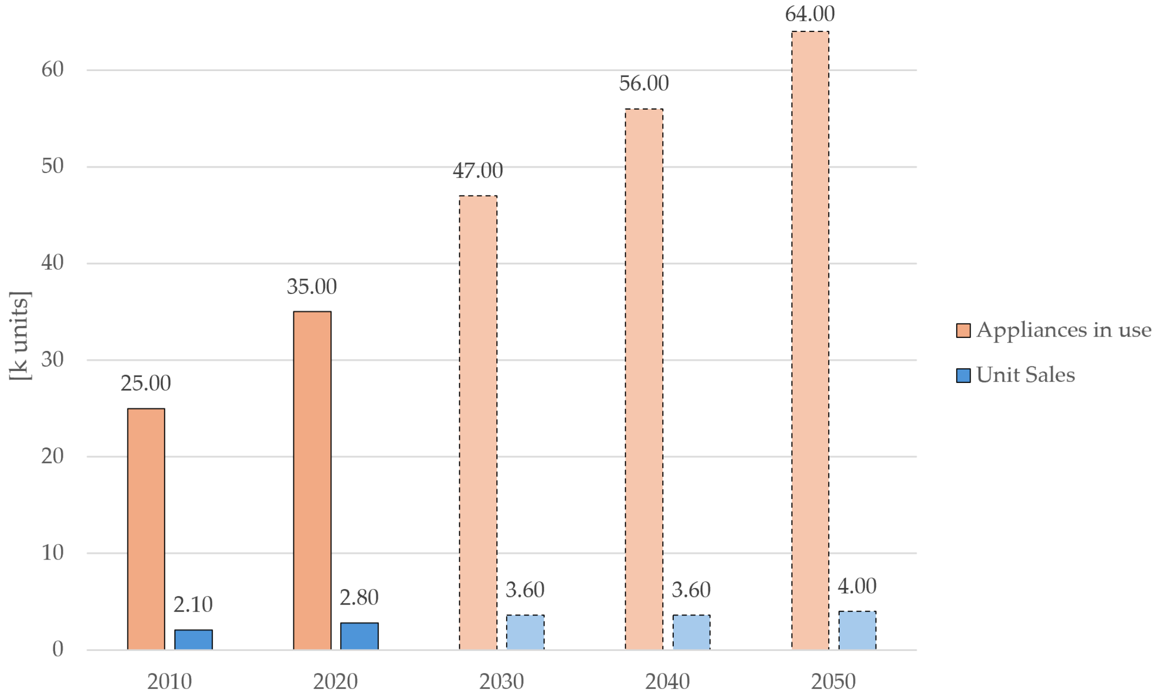
Table 13 – Ethiopia: healthcare cooling technology indicators

Indicator	Value	Source
Facilities receiving PV + cold-chain equipment (HFSE)	≈ 300 prioritised	[54]
Medical refrigerators in service (Ethiopia)	not separately published (Gavi aggregates)	[44]
Modelled AC baseline in clinical settings	DX single-split / VRF for smaller facilities	Screening assumption
Reference refrigerant for modelled chiller stock	High-GWP HFC mix represented by a regional proxy	[68]

Indicator	Value	Source
Procurement direction (hospital chillers)	R-290, NH_3/CO_2	[43]
Procurement direction (medical refrigerators)	R-600a (isobutane)	[44]
R-22 in installed base	covered by HCFC phase-out (HPMP)	[11]

Despite the dominance of split units, the centralized chiller segment is growing. Figure 7 shows a national centralized-chiller sales projection used as a general market proxy. It is not a hospital-specific sales series and should not be interpreted as evidence of the installed healthcare stock [63].

Figure 7 – Ethiopia: national centralized-chiller estimated unit sales (market proxy) [63]



Energy implications

Under the reference service scenario, the model estimates annual hospital electricity demand at about 354 GWh/yr. The central screening assumption assigns 50% of this amount to cooling, or about 177 GWh/yr, equivalent to about 0.86% of national electricity generation (20,515 GWh in 2023 [22]). A consistent cooling-only emissions boundary is used: indirect emissions are calculated from the 177 GWh cooling load, while direct emissions represent refrigerant leakage from the reference cooling systems. Grid-only cooling emissions are estimated at about 0.048 Mt CO_2eq/yr, comprising about 0.0455 Mt direct and 0.0029 Mt indirect emissions. A screening upper case in which 6.5% of cooling electricity is supplied by diesel raises the total to about 0.056 Mt CO_2eq/yr. Notably, the diesel share is a sensitivity derived from outage hours, not a measured national average for hospital generators.

Energy consumption and emissions in the healthcare sector are parameterised using hospital bed count as the primary proxy. At national level, beds per 1,000 inhabitants is a widely available indicator of healthcare-system development; at facility level, bed capacity correlates with infrastructure complexity because larger hospitals operate more specialised departments and generally consume more electricity per bed. Health posts and health centers are excluded from the energy assessment. The central case assigns 50% of total hospital electricity to cooling, consistent with published benchmarks for facilities in hot climatic zones [64]. Because a single national share is uncertain in Ethiopia's altitude-diverse climate, 35% and 65% are retained as low and high sensitivities, corresponding to about 124-230 GWh/yr of cooling electricity. The official three-tier taxonomy and facility-level registry allow each hospital to be assigned directly to its functional tier rather than inferred from size bands, mapping Primary, General and Comprehensive Specialized Hospitals onto reference levels 1, 2 and 4 respectively. The consumption values used are presented in Table 14.

The bed count of Ethiopian facilities is taken from the national facility registry rather and the average capacity of each tier is computed explicitly [50]. The registry records 602 operational hospitals with tier and, where available, inpatient beds; a bed count is reported for 431 facilities and missing for 171. The arithmetic mean of the reported values is about 42 beds across 271 Primary Hospitals, about 106 across 142 General Hospitals and about 421 across 18 Comprehensive Specialized Hospitals. The tier mean is assigned only to facilities of the same tier with a missing value. Summing reported and imputed beds gives about 16,055 Primary-Hospital beds, 19,536 General-Hospital beds and 13,898 Comprehensive-Specialized-Hospital beds, for a national total of about 49,490 [50]. Approximately 15,600 beds, or 32% of the modelled total, are imputed; uncertainty is concentrated in the specialised tier, where 15 of 33 facilities lack a reported count. The total should therefore be read as a registry-based modelled capacity rather than a fully observed inventory.

Table 14 – Healthcare reference specific energy consumption [65]

Healthcare Facility Type	Average beds	Hospital electricity consumption [kWh/bed·yr]	Consumption for cooling [kWh/bed·yr]
Primary Hospital	42	4,600.00	2,300.00
General Hospital	106	6,515.90	3,257.95
Comprehensive Specialized Hospital	421	10,988.00	5,494.00

The kWh per bed-year values are international healthcare energy benchmarks [65], mapped to Ethiopia's three hospital tiers according to clinical complexity. They are used because no national hospital energy-audit dataset is currently published. A measured Ethiopian hospital value (Boru Meda Hospital, about 11,200 kWh/day) [66] is used only as an Ethiopia-specific order-of-magnitude check, not as the basis for national extrapolation. Cooling-related GHG emissions are assessed as the sum of indirect emissions from cooling electricity and direct emissions from refrigerant leakage. Where backup generation is considered, the grid-only cooling load is split between grid and diesel supply under an explicit sensitivity case. For direct emissions, the type, size, refrigerant charge and average annual leakage of the cooling plant are inferred for each tier from the estimated facility stock. Reference data are presented in Table 15.

The calculation chain can be reproduced from the tabulated parameters:

Hospital electricity = beds by tier × kWh per bed-year

Cooling electricity = hospital electricity × cooling share (50%)

Cooling capacity = beds by tier × kW per bed

Refrigerant bank = cooling capacity × specific charge (kg per kW)

Direct emissions = refrigerant bank × annual leakage rate × GWP

Diesel emissions = cooling electricity demand × assumed diesel-supplied share × diesel emission factor

Table 15 – Reference healthcare facility cooling plant technology characteristics [67][68][81]

Healthcare Facility Type	Typical cooling system	Plant size per bed [kW/bed]	Specific charge [kg/kW] · annual leakage rate
Primary Hospital	Mostly VRF and DX split units; one or two small modular chillers may serve the operating block and ICU	8.64	0.27 · 10%
General Hospital	Chilled-water plants	12.24	0.14 · 22%
Comprehensive Specialized Hospital	Chilled-water plants	20.64	0.14 · 22%

On this basis, the modelled equivalent cooling capacity is about 665 MW and the corresponding refrigerant bank under the reference technology scenario is about 111,090 kg. The Primary Hospital reference systems, represented by VRF and DX split equipment, use a specific charge of 0.27 kg/kW and a 10% annual leakage rate; General and Comprehensive Specialized Hospitals, represented by chilled-water plants, use 0.14 kg/kW and 22% annual leakage. These parameters are transferred from Kenyan specific data as a regional proxy because Ethiopia-specific equipment data are not available [81]. Applying the weighted-average GWP of about 2,280 [68] gives direct emissions of approximately 0.0085 Mt CO_2eq/yr for Primary Hospitals, 0.0168 Mt for General Hospitals and 0.0201 Mt for Comprehensive Specialized Hospitals, or about 0.0455 Mt CO_2eq/yr in total. The national grid factor is treated separately for indirect emissions [24].

The choice of grid emission factor deserves a note because published values for Ethiopia diverge. This assessment adopts 0.0164 tCO_2/MWh [24], consistent with a generation mix that is 96.5% hydropower [22]. Applied to the 177 GWh cooling load, it gives about 0.0029 MtCO_2eq/yr of indirect emissions and a grid-only total of about 0.0484 MtCO_2eq/yr. The UNEP United for Efficiency country assessment instead adopts 0.05 kgCO_2/kWh for Ethiopia [20], roughly three times higher. Applying that factor to the same cooling load would raise indirect emissions to about 0.0089 MtCO_2eq/yr and the grid-only total to about 0.0543 MtCO_2eq/yr. Under either factor, direct refrigerant leakage remains the dominant term.

Under the central grid-only case, direct refrigerant emissions account for about 94% of the cooling footprint. Refrigerant specification, installation quality, maintenance and end-of-life recovery are therefore central procurement issues. Backup diesel can nevertheless become a material second driver. The Enterprise Survey reports about 8.2 outages per month of about 5.8 hours each [17], equivalent to roughly 571 hours per year or 6.5% of annual time. This report uses that percentage only as an upper screening case, because it does not establish what share of hospital cooling load is actually maintained by generators. Assigning 6.5% of the 177 GWh cooling load, about 11.5 GWh/yr, to diesel at 0.7 tCO_2/MWh and the remaining 165.5 GWh/yr to the grid raises indirect emissions from about 0.0029 to about 0.0108 MtCO_2eq/yr. The cooling total rises from about 0.0484 to about 0.0562 MtCO_2eq/yr and the direct share falls to about 81%. Actual values will lie between the grid-only and screening diesel cases according to generator availability, load prioritisation and operating practice. The total is also sensitive to the assumed refrigerant mix and the tier-specific leakage rates of 10% and 22%, which an equipment-level inventory would refine.

The results are summarised in Table 16.

Table 16 – Ethiopia: modelled healthcare cooling energy and cooling-only emissions under the reference service scenario

Item	Value	Unit
Estimated annual hospital electricity demand under the reference service scenario	≈ 354	GWh/yr
of which modelled cooling demand (50%)	≈ 177	GWh/yr
Cooling share of national electricity generation	≈ 0.86	%
Modelled equivalent cooling capacity	≈ 665	MW
Modelled refrigerant bank under the reference technology scenario	≈ 111,090	kg
Direct emissions (refrigerant leakage)	≈ 0.0455	Mt CO_2eq/yr
Indirect emissions (cooling electricity, grid-only)	≈ 0.0029	Mt CO_2eq/yr
Total emissions (grid-only scenario)	≈ 0.0484	Mt CO_2eq/yr
Indirect emissions (cooling electricity, 6.5% diesel sensitivity)	≈ 0.0108	Mt CO_2eq/yr
Total emissions (6.5% diesel sensitivity)	≈ 0.0562	Mt CO_2eq/yr

Direct refrigerant leakage dominates the grid-only cooling footprint, while backup generation is the clear second driver in facilities that maintain cooling loads during outages. The 6.5% diesel case is a screening sensitivity rather than a measured national average. The results support two linked priorities: low-GWP, leak-tight cooling equipment and reliable clean power, from the grid or from solar with storage, at facilities that would otherwise depend on diesel. Energy efficiency remains important for resilience and capacity, even though operating-cost savings are modest under Ethiopia's very low electricity tariffs of about USD 0.014/kWh [19].

Structural barriers to investment

Several structural barriers constrain the deployment of efficient cooling solutions across the healthcare sector. The principal ones are identified in Table 17.

Table 17 – Ethiopia: barriers to the deployment of cooling technologies in the healthcare sector

Barrier	Detail
Grid absence and instability	A large share of facilities is off-grid; about 8.2 outages/month of ~5.8h each [17]; solar electrification (HFSE) is the prerequisite before cooling. [54]
Diesel backup and service-interruption risk	Where the grid is absent or unstable, continuity depends on diesel backup and battery capacity, both costly and constrained; the residual risk is interruption of the cooling service itself. Only ~34% of SSA hospitals have reliable electricity. [55]
RAC technician shortage	Dependence on specialists; high repair cost and long downtime.
High upfront capex	Excludes smaller facilities from high-efficiency equipment without concessional finance; very low tariffs (~USD 0.014/kWh) also weaken the efficiency incentive. [19]
Direct emissions dominate under a clean grid	With a grid factor near 0.016 $kgCO_2/kWh$ [24], leakage of high-GWP refrigerants outweighs indirect emissions, making refrigerant choice and leak-tightness the primary levers. [68]
No dedicated regulatory framework	No NCAP adopted; no cooling-appliance MEPS in force. The cooling-NDC roadmap identifies further policy development, while draft refrigerant restrictions described in the KIP require confirmation of their current legal status [15][9][41][16].

Technology pathways

No formally adopted National Cooling Action Plan was identified through the sources reviewed. The 2025 roadmap for integrating cooling into Ethiopia's climate policy identifies development of a National Cooling Action Plan as a policy direction, but no adopted plan or binding completion date was identified [41]. Pending a dedicated instrument, cooling is addressed through the broader climate, energy-efficiency, Montreal Protocol, and Kigali Amendment frameworks. For project developers, the directions below provide a procurement reference and a basis for demonstrating regulatory alignment in climate-finance applications. The recommended pathways are summarized in Table 18.

Table 18 – Ethiopia: technology pathway for healthcare cooling applications

Application	Recommended technology direction
Clinical HVAC (general wards)	Inverter-driven splits, VRF, mini-chillers
ICU / high-dependency units	Semi-centralized systems with heat recovery, enthalpic recuperators, TES; target 21-23 °C, 40-60% RH
Medical storage / cold rooms	High-efficiency units, R-290 or CO_2, digital monitoring, 2-8 °C continuous
Vaccine cold chain (off-grid / grid-unstable)	Solar Direct Drive (SDD) refrigerators with battery/thermal storage, the top priority given low electrification. [54][44]
Building envelope (new / retrofit)	Cool roofs, natural ventilation, shaded envelopes
Financing	Cooling as a Service (CaaS), on-bill financing, Gavi CCEOP, World Bank, Green Climate Fund. [54]

Quick summary

The key barriers and enablers for sustainable cooling investment in the healthcare sector are summarised in Table 19.

Table 19 – Ethiopia: healthcare cooling quick summary

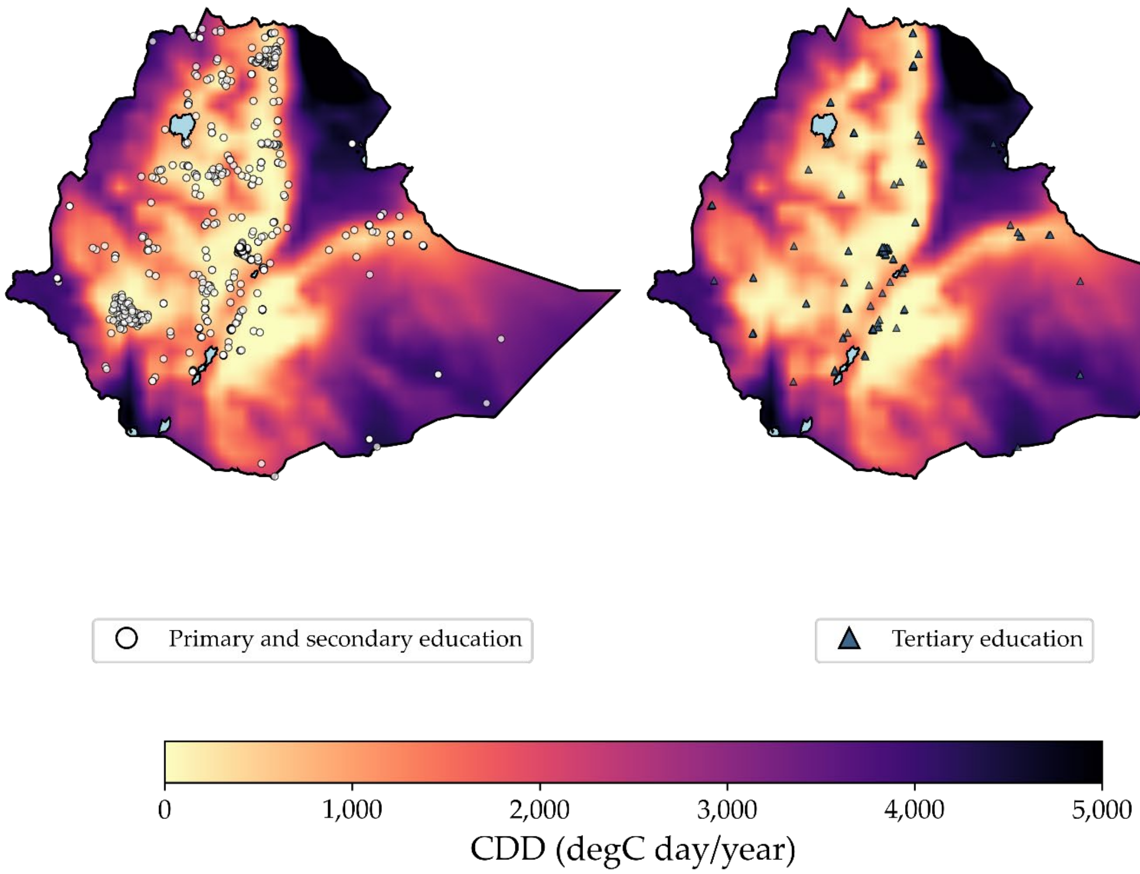
Dimension	Barriers	Enablers
Energy infrastructure	Large off-grid share; grid instability (~8.2 outages/month); diesel backup and battery constraints. [17]	HFSE (~300 facilities, PV + cold chain); growing SDD deployment; ~100% renewable generation mix. [54][14]
Technology & maintenance	Predominantly low-efficiency equipment; critical shortage of RAC technicians; high repair cost.	Transition to inverter VRF and mini-chiller systems; R-290 and CO_2 in new cold rooms. [43]
Financing	High upfront capex excludes smaller facilities; limited access to concessional finance.	Gavi CCEOP grants; HFSE (~USD 35 m); World Bank and GCF; emerging CaaS and on-bill models. [54]
Regulatory & policy	No NCAP adopted; no MEPS for AC/refrigeration. The cooling-NDC roadmap and draft refrigerant provisions in the KIP require confirmation against the current official framework [15][9][41][16].	Kigali ratified (2019); CRGE/NDC framework; A5 low-GWP preferences. [13][43]
Emissions	Direct refrigerant emissions dominate the grid-only cooling footprint (~94%); the share falls to ~81% in the 6.5% diesel sensitivity. [24][68]	Very low grid emission factor (~100% hydro); headroom for low-GWP refrigerants. [14]
Demand & demography	Official provision ≈ 0.32 beds/1,000 in 2016; registry/modelled capacity ≈ 0.36-0.37 beds/1,000; ~254/122/22 facility equivalents by 2050 at current ratios. [51][50][5]	Quantified long-term demand signal; ~177 GWh/yr cooling requirement; active donor engagement. [5]

Education

System structure and context

Ethiopia's education system serves one of the youngest and fastest-growing populations in the world. General education is organized across pre-primary, primary (six years, official ages 7-12), middle and lower-secondary, and a two-year upper-secondary cycle, followed by a tertiary sector led by a rapidly expanded public university system [69][14], all operating under the national education sector development programme [70]. Enrolment is large in absolute terms, about 19.8 million learners from pre-primary through secondary in 2023/24 [71], with primary enrolment of roughly 15.9 million and secondary enrolment of about 5.0 million [72]. The two figures come from different sources and definitions and should not be added: the 19.8 million is the Ministry of Education aggregate for a single reporting year [71], whereas the by-level figures are UIS gross enrolment [72], which counts over-age and under-age pupils and therefore exceeds the net school-age population. Primary participation has risen toward near-universal gross coverage, but the system thins sharply at higher levels. The secondary gross enrolment ratio stands at about 36.6%, and only 3,174 secondary schools serve the entire country [71]. The geographic distribution of education facilities relative to thermal stress is shown in Figure 8.

Figure 8 – Ethiopia: Education facilities location vs cooling degree days 18°C distribution



Classroom conditions are shaped by crowding and by a severe infrastructure deficit. Average class sizes are large: the primary pupil-to-teacher ratio is high and reaches its most acute levels in the lowland peripheries, where one section may hold sixty or more pupils [73]. The binding constraint on any form of active cooling, however, is electricity: at primary and middle level only about 28.5% of schools are connected to power, a functional laboratory exists in only 10.9% of schools, a functional library in 38.7%, and clean drinking water in 35.5% [71][74]. More than three-quarters of elementary schools lacked electricity as recently as 2015 [75], against a national electricity-access rate of about 55% [8]. Key indicators are summarised in Table 20.

Table 20 – Ethiopia: education sector key indicators[2]

Indicator	Value	Source
Learners (pre-primary to secondary, 2023/24)	≈ 19.8 million	[71]
Primary enrolment	≈ 15.9 million	[72]
Secondary enrolment	≈ 5.0 million	[72]
Tertiary enrolment	≈ 587,000	[72]
Secondary gross enrolment ratio	≈ 36.6%	[71]
Secondary schools (national)	3,174 [76]	[71]

[2] The 2023/24 statistical abstract excludes the Tigray region and uses prior-year data for Amhara, so national figures somewhat undercount the true estate; the orders of magnitude, however, are robust and are the basis for the demand model below.

Indicator	Value	Source
Primary/middle schools with electricity	≈ 28.5%	[71]
Schools with a functional laboratory	≈ 10.9%	[71]
Schools with clean drinking water	≈ 35.5%	[71]

The thermal problem

The thermal challenge in Ethiopian schools is sharply regional. The temperate highlands, where most schools and pupils are located, are comparatively mild for much of the year, so the dominant comfort and learning constraints there are crowding and the absence of basic services rather than heat. In the arid and semi-arid lowlands, by contrast, classroom overheating is acute, and these are precisely the regions, Afar, Somali, Gambela, Benishangul-Gumuz and the lowland margins of Oromia and the southern regions, that already record the highest pupil-to-teacher ratios, the lowest enrolment ratios and the weakest infrastructure [73][71]. Lightweight corrugated-iron roofing, widespread across the school estate, absorbs solar radiation intensely and drives indoor temperatures well above comfort thresholds during peak hours, while natural ventilation and shading are typically insufficient to offset the gain.

Two structural features compound the exposure. First, mechanical cooling penetration in primary and secondary schools is effectively negligible, so in the hot lowlands there is no active mitigation in place. Second, overcrowding obliges many schools to operate multiple daily shifts, which pushes a substantial share of teaching into the afternoon, when indoor temperatures peak, so the hours of greatest learning effort frequently coincide with the hours of greatest heat stress. Excess classroom heat is associated with impaired concentration and weaker learning outcomes [77], a burden that falls most heavily on the lowland regions that are already furthest behind. Underlying all of this is the electricity constraint. With fewer than three in ten primary and middle schools connected to power [71], active cooling is not a near-term option for the great majority of the estate, and the realistic response in those schools is passive thermal design.

Market trajectory

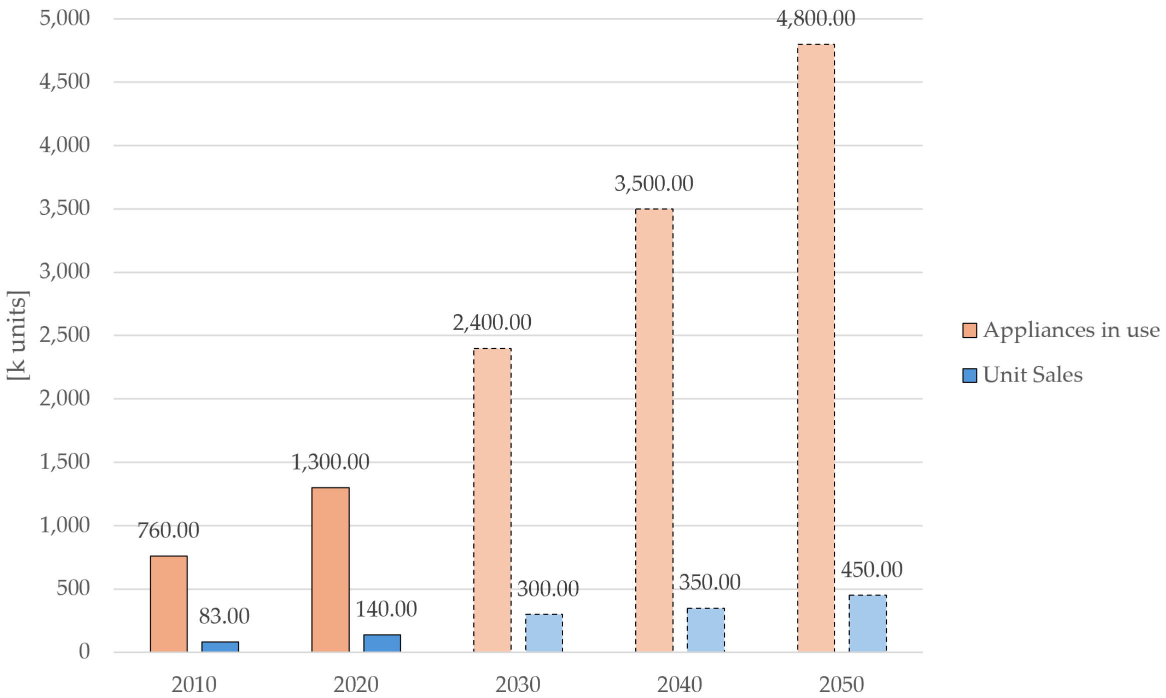
Mechanical cooling in the education sector is at a very early stage and is concentrated where reliable grid access and institutional procurement capacity make it viable: public university campuses and a subset of urban secondary schools, although underlying demand is expected to rise as warming and grid expansion proceed [78]. Across the much larger primary and middle-school estate, fans and natural ventilation remain the only mitigation where any exists. The near-term equipment mix is expected to be dominated by direct-expansion split units, while centralised chilled-water plant is relevant mainly to larger tertiary institutions. Indicative efficiencies are given in Table 21.

Table 21 – Ethiopia: education cooling technology benchmarks

Technology	COP / EER [W/W]	Notes
Modern inverter split	3.5 – 4.5	Strong part-load performance; lowest-energy mechanical option for classrooms
Conventional fixed-speed split	2.6 – 3.2	Common in lowest-price procurement; locks in low efficiency for the unit's life
Centralised chiller (tertiary)	COP ≈ 2.26	Reference plant for university campuses
Evaporative cooler	n/a	Low energy and well-suited to the dry highland climate; limited effect in humid lowlands

Figure 9 shows a national split and multi-split sales projection used only as a market proxy; it is not an education-specific sales series [63].

Figure 9 – Ethiopia: national estimated unit sales of split and multi-split systems (market proxy) [63]



Demand Estimation Methodology

Cooling energy demand is estimated through a bottom-up model structured around the Ethiopian education system. Universities are represented by a centralized-chiller reference system, while primary and secondary classrooms are represented by split or multi-split systems. For non-university facilities the calculation combines classroom load, climatic-zone utilization and scenario adoption. Adoption and utilization are multiplied within each climatic zone before national aggregation so that the two correlated assumptions are not averaged separately.

The classroom reference interior load is set at 200 W per occupant, rounding the representative interior load of 196.43 W/person reported for education facilities [80]. The teaching-building case also uses an outdoor-air rate of 8 l/s per person [80]. It is not intended to replace a project-specific ventilation calculation under the applicable design standard. Ventilation and exterior-envelope gains are not modelled separately, so the resulting screening estimates must not be used for project-level equipment sizing.

Table 22 – Ethiopia: assumed design parameters for an education plant

Parameter	Value	Reference
Screening outdoor-air rate	8 l/s per person	Source-case parameter reported for context [80]
Indoor set-point temperature	28 °C	Contextual set-point
Outdoor design temperature	35 °C	Contextual outdoor condition
Aggregate peak classroom thermal load per occupant	200 W per person	[80]
Average split system COP	3.2	[81]
Average centralized chiller COP	2.26	[81]

For each classroom, the representative interior load of 200 W per occupant is multiplied by the assumed class size and used directly as the classroom thermal load, with no additional multiplier applied: 55 occupants give 11.00 kWth at primary level and 25 occupants give 5.00 kWth at secondary level. Because the source value already combines occupant, lighting and equipment gains, those interior components are not added separately. Electrical input is obtained by dividing the classroom thermal load by the split-system COP of 3.2.

Table 23 – Ethiopia: classroom characteristics (from the classroom thermal model)

Level	Occupants/class	Interior load per occupant [W]	Classroom thermal load [kWth]	Electrical [kWel]
Primary	55	200	11.00	3.44
Secondary	25	200	5.00	1.56

Annual cooling demand is weighted by the regional distribution of the formal school estate. For each climatic zone, the share of schools, scenario air-conditioning adoption and active-cooling utilization are combined in the same term. These are serviced-cooling scenario assumptions, not measured penetration. The school year is set at 190 days with 7 operating hours per day, consistent with the national academic calendar [82].

The weighting is derived from the national school census rather than from population shares, since the location of the estate, not of the population, determines its cooling exposure. Of the 45,534 formal schools recorded, 41,297 (90.7%) lie in the temperate highland regions, 3,844 (8.4%) in the arid and semi-arid lowland regions of Afar, Somali, Benishangul-Gumuz, Dire Dawa and Harari, and 393 (0.9%) in the hot humid lowlands of Gambella [76]. Because the census assigns schools at region level, schools sited in lowland woredas within predominantly highland regions are counted as highland, so this allocation is deliberately conservative and yields a lower bound on cooling demand. The resulting zonal assumptions are set out in Table 24.

Table 24 – Ethiopia: assumed cooling-technology adoption and utilization

Climatic zone	Share of formal schools	Assumed AC adoption rate	Days with active cooling
Hot / humid lowland	0.9%	70%	60% of school days
Arid / semi-arid lowland	8.4%	60%	60% of school days
Temperate highlands	90.7%	5%	10% of school days
School-weighted average	100%	10.2% (descriptive average)	14.7% of school days (descriptive average)

The separate school-weighted averages are 10.2% adoption and about 195 potential active-cooling hours per year, but these descriptive averages must not be multiplied because the highest adoption and utilization occur in the same hot zones. The correct zone-integrated effective cooling time is:

Effective adopted cooling hours = 1,330 h/yr × sum over zones (zone share × adoption × utilization) = approximately 51.3 h/yr in the school-weighted central scenario. The adoption rates remain scenario assumptions; current mechanical-cooling penetration is negligible across most of the school estate.

Table 25 - Ethiopia: education cooling demand by level (central school-weighted scenario)

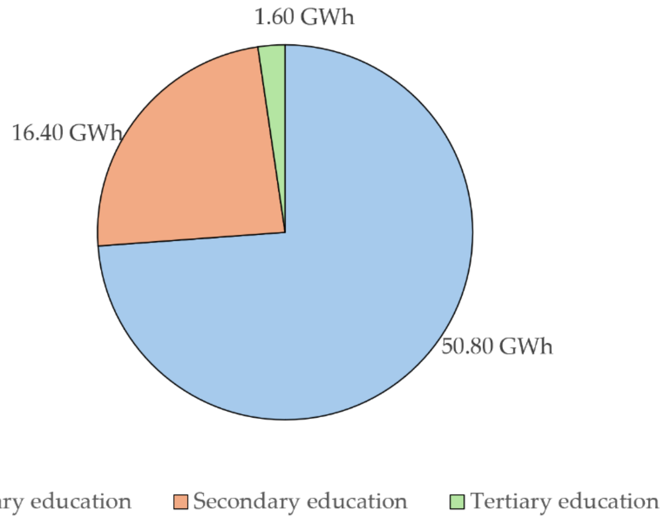
Level	Enrolment	Occupants /class	Classrooms	Electrical [kW/class]	Method	Effective h/yr	GWh/yr
Primary	15.9 M	55	287,896	3.44	Zone-integrated	51.3	50.8
Secondary	5.0 M	25	204,418	1.56	Zone-integrated	51.3	16.4
University	0.59 M	centralized	-	-	Zone-integrated	24.3	1.3
Total	-	-	-	-	-	-	68.5

For the university sector, consumption is estimated from enrolled student numbers (about 587,000 [72]), the same representative interior load of 200 W per occupant used for classrooms, an assumed annual occupancy of

630 hours and a centralized-chiller COP of 2.26 [81]. Reusing this load for universities is well supported: the underlying measurement was taken in a university teaching building [80], so no separate assumption is introduced for this level. The same zone-coupled adoption and utilization factor is applied, giving approximately 24.3 effective adopted cooling hours and about 1.3 GWh/yr. On the same basis, primary-school demand is about 50.8 GWh/yr and secondary-school demand about 16.4 GWh/yr, as set out in Table 25. The central total is therefore about 68.5 GWh/yr after rounding. This is roughly 0.33% of national electricity generation [22] and corresponds to an annual electricity cost of approximately USD 0.7-2.7 million across the residential tariff range used in this report [18][19][20].

The estimate is a serviced-cooling scenario rather than observed current consumption. It represents demand that could emerge if limited active cooling were introduced in the most exposed and electrified parts of the education estate. The result remains sensitive to classroom load, climatic allocation, adoption and utilization assumptions.

Figure 10 – Ethiopia: cooling energy demand by education subsector in central scenario



Emissions Estimation

Total emissions are the sum of indirect emissions from electricity consumption and direct emissions from refrigerant leakage. Applying the national grid factor of about 0.0164 tCO_2/MWh [24] to the central electricity demand of 68.5 GWh/yr gives about 1.1 $ktCO_2$/yr. Direct emissions are estimated from the installed system count, charge and annual leakage. The weighted-average GWP, based on IPCC Fourth Assessment Report values [83], is derived from the assumed split-system refrigerant mix in Table 26.

Table 26 – Ethiopia: split & multi-split systems refrigerant adoption share

Refrigerant	Assumed share	GWP (AR4)
R-410A	80%	2,088
R-407C	20%	1,770
Weighted average GWP	100%	≈ 2,024

An average initial charge of 5.75 kg is assumed per installed classroom split or multi-split system, with annual leakage equal to 10% of charge. In the central school-weighted scenario, the 10.205% adoption average applied to 492,314 primary and secondary classrooms gives about 50,241 installed systems. The non-university direct-emission calculation is therefore 50,241 × 5.75 kg × 10% × 2,024, or about 58.5 $ktCO_2eq$/yr. Centralized university plant is treated separately, using the same chiller charge ratio and annual leakage rate as the General and Comprehensive Specialized Hospital chillers (0.14 kg/kW and 22%) and the same weighted-average chiller

GWP of about 2,280 [68]. The adoption-weighted installed capacity is about 11,980 kWth, giving a refrigerant bank of about 1,680 kg, of which about 370 kg leaks per year, for direct emissions of about 0.8 ktCO_2eq/yr. The charge and leakage assumptions are major uncertainties and should be refined with local equipment data.

Table 27 – Ethiopia: education cooling emissions summary

Emission component	Value [ktCO_2/yr]
Indirect emissions – electricity consumption	≈ 1.1
Direct emissions – refrigerant leakage (non-university)	≈ 58.5
Direct emissions – refrigerant leakage (university)	≈ 0.8
Total estimated emissions	≈ 60.4

Because the grid is almost entirely hydro-based, direct refrigerant leakage accounts for about 98% of the central footprint. The decisive mitigation levers are therefore refrigerant GWP, leak-tight installation, maintenance and end-of-life recovery. Efficiency remains important for grid capacity and resilience even though it contributes little to the emissions total under the current grid mix.

The estimate is particularly sensitive to spatial allocation. The population-weighted sensitivity uses the same coupled calculation but substitutes an assumed climatic distribution of 5% hot/humid lowland, 20% arid/semi-arid lowland and 75% temperate highlands. Its zone-integrated effective time is about 128.7 hours per year, not the product of separate average adoption and utilization values. On the same classroom-load basis, the resulting electricity demand is about 172 GWh/yr, compared with about 68 GWh/yr in the school-census-weighted central case. Direct and indirect emissions rise to about 115 ktCO_2eq/yr, compared with about 60 ktCO_2eq/yr centrally. The screening range is therefore approximately 68-172 GWh/yr and 60-115 ktCO_2eq/yr. The school-census-weighted case is better grounded for the existing estate. The population-weighted case is intended as a hotter spatial sensitivity, not a forecast.

Two-segment intervention logic

The education cooling challenge divides into two structurally distinct segments that call for different responses. The first, and by far the larger, covers rural and off-grid schools: with fewer than three in ten primary and middle schools connected to power [71], the majority of the estate cannot support mechanical cooling in the near term, and passive thermal design is the primary and most immediately scalable intervention. Applicable strategies include solar-reflective roof coatings, replacement of bare corrugated-iron roofing with insulated or ventilated assemblies, natural ventilation through stack effect and cross-ventilation, solar shading through fins and recessed windows, higher-thermal-mass construction, evaporative cooling in the dry highlands, and nature-based measures such as shade-tree planting. These measures deliver meaningful temperature reductions at low incremental cost, and the investment case is framed around learning outcomes and climate resilience rather than energy savings, with financing routes through development finance aligned with SDG 4, climate-adaptation funds such as the Green Climate Fund, and national and regional construction budgets [84][15].

The second segment covers urban and institutional facilities, universities, urban secondary schools and administrative buildings with reliable grid access. Here multi-split and VRF systems are the relevant technology, and the priority is to set a high-efficiency, low-GWP baseline before low-efficiency, high-GWP defaults consolidate. Inverter-driven equipment, minimum-efficiency procurement criteria, refrigerants consistent with Ethiopia's commitments under the Kigali Amendment [13], and on-site solar integration are the key elements. Because the market is still at a formative stage, there is a clear early-mover opportunity to embed efficiency and low-GWP standards in public procurement before the installed base locks in.

The resulting hierarchy is explicit. For most primary and middle schools, especially where electricity is absent or unreliable, passive cooling is the near-term intervention space: roof reflectance, shading, cross-ventilation, ceiling height, classroom orientation and timetable management. Mechanical cooling becomes relevant first for universities, laboratories and ICT rooms, urban secondary schools and selected lowland facilities with reliable electricity. The policy objective in the school estate is therefore less to install cooling than to prevent a future market from developing around inefficient, high-GWP equipment.

Quick summary

The key barriers and enablers for sustainable cooling investment in the education sector are summarised in Table 28.

Table 28 – Ethiopia: education sector cooling quick summary

Dimension	Barriers	Enablers
Energy infrastructure	Only ~28.5% of primary/middle schools electrified; grid unreliability where connected. [71]	Electrification programmes; abundant solar resource; ~100% renewable generation mix. [14]
Building stock	Corrugated-iron roofing and lightweight construction; no passive-cooling standard in the building code.	Passive design (cool roofs, ventilation, shading, thermal mass) delivers low-cost reductions, especially in hot lowlands. [84]
Financing & procurement	Mechanical cooling beyond most school budgets; donor-dependent cycles; limited passive-design capacity.	SDG 4-aligned development finance; climate-adaptation funds; Cooling-as-a-Service for the electrified segment. [15]
Market maturity	Near-zero mechanical penetration in primary/secondary; risk of low-efficiency default.	Formative market offering early-mover advantage to set high-efficiency, low-GWP baselines.
Emissions	Direct refrigerant leakage dominates (~98%) under the clean grid: refrigerant choice and leak-tightness are critical. [24]	Very low grid emission factor; headroom for low-GWP refrigerants under Kigali. [13]
Demand & demography	Very young, fast-growing population; large unmet infrastructure need; lowland regions hottest and least served. [71][73]	Central demand signal (~68 GWh/yr); hotter population-weighted sensitivity ~172 GWh/yr; active donor engagement; CRGE/NDC framework. [15]

Food Cold Chain

Structural duality: export vs. domestic

Ethiopia's agrifood cold chain is characterised by a pronounced structural duality. On one side sits a small but technically demanding export segment, oriented toward high-value perishables, cut flowers, in which the country is the second-largest African exporter, alongside fresh fruit and vegetables, and served by purpose-built handling at air-cargo and dry-port hubs [85][86]. On the other sits a domestic cold chain that remains fragmented, underdeveloped and largely inaccessible to the smallholder farmers, typically cultivating less than two hectares, who constitute the productive backbone of the national food system [87]. A defining feature shapes the whole system: Ethiopia is landlocked, so every refrigerated export must move overland to a maritime gateway, principally the port of Djibouti, reached through the Modjo dry port and the Ethiopia-Djibouti railway, or leave by air [88][87]. Understanding this duality is essential for any project developer assessing market entry, as the two segments present fundamentally different demand profiles, financing constraints and technology requirements. The key dimensions of the contrast are summarised in Table 29.

The two segments are not two versions of the same market. The export segment is a compliance and corridor-integration problem. The domestic segment is an aggregation, affordability and service-model problem. Treating both as a generic cold-chain market would lead to the wrong technology and the wrong financing choices.

The export corridor has begun to acquire dedicated cold-chain assets. Cool Port Addis, located at the Modjo dry port about 70 km from the capital, provides refrigerated consolidation for horticultural exports moving to the port of Djibouti, and in November 2024 Ethiopia completed its first refrigerated sea export of vegetables, a 12-tonne consignment of sugar snap and mangetout peas shipped to the Netherlands through Djibouti [87][89]. Ethiopian Airlines has in parallel expanded its perishables terminal to about 450,000 tonnes per year [88][89][90]. The prize is large: reducing post-harvest losses at the scale currently lost would release food equivalent to the annual consumption of about 23 million people [88].

Table 29 – Ethiopia: export vs. domestic cold chain structural comparison

Dimension	Export segment	Domestic segment
Maturity	Small, specialised, growing	Fragmented; largely absent at farm level
Key products	Cut flowers (2nd in Africa [85]), fresh fruit and vegetables; coffee (dry, non-reefer) is the largest export by value [91]	Dairy, horticulture, fresh meat, inland fisheries
Primary logistics	Modjo dry port to the port of Djibouti by the Ethiopia-Djibouti railway and road; air freight via Addis Ababa [88][90]	Farm to local market, mostly unrefrigerated
Core technology	Reefer containers, pre-cooling, pack-house and air-cargo cold chain	Modular cold rooms, solar cooling-as-a-service, evaporative storage
Post-harvest losses	Logistics-driven (corridor dwell, border delays) [87]	30-50% for horticulture; ~30% for milk [31]
Investment logic	Precision, compliance, international standards	Affordability, simplicity, grid-unstable / off-grid design
Financing	Export-revenue-backed, commercial	Concessional, cooling-as-a-service, cooperative aggregation

Ethiopia also holds the largest livestock population in Africa, yet its formal meat and dairy processing cold chain is still nascent. Most slaughter is informal and meat is sold and consumed fresh on the day, so the industrial blast-freezing and cold-storage capacity that dominates the cold-chain energy footprint of large meat-exporting economies is largely absent here [92]. This keeps the energy estimate below centred on the movement and storage of perishables rather than on in-plant process refrigeration.

Export cold chain: key logistics vulnerabilities

The export segment, though relatively sophisticated, is exposed to a chain of infrastructure bottlenecks that individual project developers cannot resolve unilaterally but must design around. The landlocked corridor to the sea is the defining constraint: refrigerated cargo must travel several hundred kilometres from the central production belt to the Modjo dry port and on to Djibouti before it reaches a ship, with each leg adding dwell time and temperature-excursion risk. The principal vulnerabilities, their impact on cargo integrity and the recommended interventions are identified in Table 30.

Table 30 – Ethiopia: export cold-chain infrastructure bottlenecks

Bottleneck	Impact	Addressable solution
Landlocked corridor to Djibouti (several hundred km of rail/road haul)	Long transit; cumulative dwell; temperature-excursion risk before shipment [88][87]	Reefer telemetry; corridor cold-chain and pre-cooling at Modjo
Ethiopia-Djibouti railway: limited reefer plug-in capacity	Reliance on diesel gensets (higher cost and emissions)	Reefer electrical connections along the rail corridor
Modjo dry port / Cool Port Addis throughput	Congestion and extended dwell for perishables [88]	Cold-store and reefer-yard capacity expansion

Bottleneck	Impact	Addressable solution
No shore power for Ethiopian reefer cargo at the maritime gateway	Temperature-integrity risk during port handling	Shore-power access and cold-ironing arrangements
Customs and phytosanitary throughput at the border	Weekend/holiday bottlenecks for time-critical perishables	Continuous (7/365) inspection for perishable lanes
Air-freight cost exposure	Perishable air-freight tariffs raised ~20% from April 2026, pressuring a cost-sensitive export base [93]	Volume consolidation; modal balance between air and sea reefer

These bottlenecks are not marginal operational inconveniences. For temperature-sensitive cargo, each gap in the cold chain translates directly into product loss, market rejection or reduced export value. Project developers should treat infrastructure redundancy and temperature monitoring as non-negotiable design requirements rather than optional enhancements.

Energy demand and system-wide GHG footprint

The system boundary used here intentionally combines two components: operational emissions from a serviced cold chain (electricity, diesel backup and refrigerant leakage) and spoilage-related emissions associated with food that is lost before consumption. Spoilage emissions remain within the boundary to represent the climate relevance of loss reduction, while Table 31 reports the operational and spoilage components separately.

Table 31 – Ethiopia: food cold chain estimated energy demand and GHG footprint (estimate)

Segment	Estimated energy demand / GHG emissions	Notes
Domestic cold storage (perishables)	≈ 249 GWh/yr	≈ 11.4 Mt refrigerated domestic perishables
Export pre-shipment cold storage	≈ 13 GWh/yr	≈ 0.6 Mt refrigerated exports
Reefer transport (export, corridor)	≈ 18 GWh/yr	Export tonnage via TEU; 2.1 kW/TEU, equivalent to 4.2 kW per 40-foot reefer (see methodology)
Estimated electricity demand under a serviced cold-chain scenario	≈ 279 GWh/yr	≈ 1.36% of national electricity generation [22]
Spoilage (food-loss) emissions	≈ 5.36 Mt CO_2eq/yr (screening proxy)	≈ 8 Mt perishables lost × 0.674 tCO_2eq/t [94]
Direct refrigerant leakage (system)	≈ 0.0176 Mt CO_2eq/yr	Cold storage ≈ 0.015 + reefers ≈ 0.0026 [68]
Energy-related emissions (grid)	≈ 0.005 Mt CO_2eq/yr	279 GWh/yr × 0.0164 tCO_2/MWh [24]
Energy-related emissions (with backup diesel)	≈ 0.017 Mt CO_2eq/yr	≈ 6.5% of load on diesel gensets [17]
Total system-wide GHG footprint (including food loss)	≈ 5.40 Mt CO_2eq/yr	Spoilage ≈ 99.4% of the total; cold-chain operational emissions ≈ 0.035 Mt CO_2eq/yr

Because product-specific footprints differ across horticulture, roots and tubers, dairy and meat, the food-loss figure is best interpreted as a strategic system-wide estimate rather than as a product-level life-cycle assessment. Food-loss emissions remain inside the assessment boundary by design, but they are distinguished from the cold chain's own operational emissions. The refrigerant and backup-diesel estimates are screening figures based on assumed equipment capacities, charges, leak rates and refrigerant mixes that are not documented at national level. Neither qualification changes the conclusion: spoilage dominates the combined footprint, while low-GWP refrigerants, leak-tightness and reliable clean power keep operational emissions comparatively small.

The estimate is a food-flow model of the potential refrigeration-relevant throughput under a serviced cold-chain scenario, not a metered inventory of existing cold-chain electricity consumption; the domestic cold chain is today largely absent, so the roughly 12 Mt of refrigerated throughput is a potential, not a current, figure. It is designed to quantify the scale of the opportunity created by avoidable food losses and by the gradual formalization of the domestic and export cold chains. The refrigeration-relevant perishable throughput is built up from fruit and vegetables (about 9 Mt), roots and tubers (about 6 Mt), milk (about 3.8 Mt) and meat (about 1.2 Mt), giving an annual perishable throughput on the order of 20 Mt [95][96]; the dairy and meat figures follow national livestock statistics [97][92]. Applying a post-harvest loss rate of about 40%, within the documented national range of 30-50% for horticulture and around 30-40% for animal products [31], yields roughly 8 Mt of perishables lost each year and about 12 Mt of refrigerated throughput, of which a small share (around 5%) enters the export chain and the remainder serves the domestic market.

Cold-chain energy is estimated in two parts. Reefer-transport consumption is derived from refrigerated export tonnage, converted at 12 tonnes per TEU and operated for an assumed 168 connected hours across the in-country legs. The electrical-power parameter is anchored to measured operating data from the Port of Mombasa reported in the accompanying port-energy technical note: approximately 4.2 kW for a 40-foot reefer, equivalent to 2.1 kW per TEU because one forty-foot equivalent unit equals two TEU [98]. The Mombasa measurements are not publicly available and are used as a regional operational proxy, not as an Ethiopian national average. Cold-storage consumption applies a benchmark of about 21.8 kWh per tonne of annual throughput to both export pre-shipment and domestic perishable streams. The 5% export share, 12 t/TEU payload, 168 connected hours and 21.8 kWh/t storage intensity remain screening assumptions. Actual consumption varies with product temperature, turnover, insulation, door openings, pre-cooling and backup operation.

System-wide GHG emissions include energy-related and spoilage-related emissions. The latter use a generic end-of-life proxy of 0.674 tCO_2eq per tonne of food waste sent to landfill with gas recovery, sourced from New Zealand Ministry for the Environment data through Climatiq [94]. This factor is not Ethiopia-specific and is not a product-level cradle-to-gate footprint. Approximately 8 Mt of losses therefore correspond to about 5.36 $MtCO_2eq$/yr under the screening proxy. Grid electricity contributes only about 0.005 $MtCO_2eq$/yr under the 0.0164 tCO_2/MWh grid factor [24][22]. The serviced cold-chain electricity demand of about 279 GWh/yr corresponds to roughly 1.4% of national generation [22] and about USD 3.9 million/yr at the tariff used in this assessment [19]. Because spoilage emissions are intentionally retained within the boundary, they account for almost all of the combined footprint. Reducing losses toward the approximately 9% rate used as an advanced-system comparison would avoid on the order of 4 $MtCO_2eq$/yr under the same proxy, subject to product-specific life-cycle factors and verified disposal pathways.

Two operational sources complete the system-wide footprint. Modelled equivalent cooling capacity inferred from about 262 GWh/yr of cold-storage electricity, 4,000 equivalent full-load hours and a COP of 2.5 is about 164 MW. The export flow of about 50,000 TEU-equivalent movements per year corresponds to roughly 960 TEU-equivalents connected at any one time under the model assumptions, equivalent to about 480 physical 40-foot reefers because each 40-foot unit counts as two TEU. Applying the stated charge, leakage and GWP assumptions to the physical units gives about 0.0176 $MtCO_2eq$/yr of direct refrigerant emissions, approximately 0.015 Mt from cold storage and 0.0026 Mt from reefers [68]. Backup diesel is treated as a sensitivity: applying a 6.5% grid-unavailability case [17] and 0.7 tCO_2/MWh raises energy-related emissions from about 0.005 to about 0.017 $MtCO_2eq$/yr. This percentage is not a measured share of cold-chain electricity generated by diesel. Combining about 5.36 Mt of spoilage emissions, 0.0176 Mt of refrigerant emissions and 0.017 Mt of energy emissions gives approximately 5.40 $MtCO_2eq$/yr after rounding. Spoilage contributes about 99.4% of the total. The cold chain's own operational emissions are about 0.035 $MtCO_2eq$/yr. Low-GWP refrigerants, leak-tight installation, recovery and reliable clean power are therefore necessary to keep operational emissions marginal while the cold chain delivers its much larger loss-reduction benefit.

Market drivers and projections

Several structural forces are converging to drive cold chain market growth over the coming decade. The key drivers and their projected impact are summarised in Table 32.

Table 32 – Ethiopia: food cold chain market drivers

Driver	Detail
Export volume growth	Cut flowers (second-largest African exporter) and a widening fresh fruit and vegetable base; first refrigerated sea export of vegetables to Europe via Djibouti in 2024, signalling a shift from air toward sea reefer [89][85]
Urbanisation-led domestic demand	A large, fast-urbanising population is raising demand for fresh, retail-ready and processed food, creating a refrigerated-distribution pull in and around the major cities
Climate adaptation	Warming compresses the harvest-to-spoilage window and widens the addressable market for cold storage beyond the current perimeter
Projected market value	Commercial market estimates indicate a rapidly expanding cold-chain logistics market, from about USD 323 m (2024) to about USD 917 m (2033), around 12% per year, consistent with the structural drivers identified in this section [32]

Taken together, these drivers create a demand signal that is both large and durable. The combination of export growth, urbanisation-led domestic consumption and climate-driven market expansion means that cold chain investment is not dependent on any single growth vector, reducing the risk profile for long-term infrastructure commitments.

Barriers and technology priorities

The principal barriers constraining cold chain development are identified in Table 33.

Table 33 – Ethiopia: food cold chain investment barriers

Barrier	Detail
Energy insecurity	Grid outages at cold-chain nodes and a large off-grid rural base undermine continuous refrigeration; back-up diesel raises cost and emissions
Smallholder affordability	Modular off-grid cold rooms are beyond smallholder reach without grant or concessional finance; the constraint is a business-model gap rather than a technology gap [87]
Landlocked corridor dependence	Reliance on the Djibouti gateway, with long rail/road haul, border formalities and air-freight cost exposure [88][93]
Financing gap	Cooling-as-a-service, cooperative aggregation and output-linked finance are more effective than equipment supply alone
Loss and infrastructure data	Post-harvest-loss monitoring and cold-store metering remain weak, limiting investment targeting [31]

The financing barrier deserves particular attention. At the smallholder end of the market, the constraint is not the absence of suitable technology but the inability to mobilise upfront capital. Interventions that address this through service-based procurement models and cooperative aggregation are likely to achieve greater scale and sustainability than those focused on equipment supply alone.

Technology and intervention priorities

The recommended technology and intervention priorities, organized by axis and target segment, are set out in Table 34.

Table 34 – Ethiopia: cold chain technology and intervention priorities

Technology / intervention axis	Target segment	Key design requirements
Solar and hybrid modular cold rooms; cooperative aggregation and cooling-as-a-service	Domestic smallholder, dairy and horticulture	Off-grid or hybrid PV; low-GWP refrigerants (R-290, R-600a); simple operation and maintenance; output-linked finance
Consolidation centres with pre-cooling and blast chilling	Export horticulture	Renewable-energy integration; aggregation of smallholder volumes; export-standard temperature protocols
Low-GWP commercial refrigeration	All segments	Natural and low-GWP refrigerants consistent with Ethiopia's Kigali commitments [13]; leak-tight design and end-of-life recovery
Corridor cold chain: reefer plug-in and shore power	Export: Modjo dry port and the Djibouti rail/road corridor	Reefer telemetry; electrical connections along the corridor; cold-store capacity

The two segments require distinct intervention logics: the export segment demands precision, compliance and integration with international cold-chain standards, while the domestic segment demands affordability, operational simplicity and solutions designed for grid-unstable or off-grid deployment. Across both, the dominant climate lever is the same, reducing the post-harvest losses that drive almost the entire footprint.

Quick summary

The key barriers and enablers for sustainable cold chain investment are summarised in Table 35.

Table 35 – Ethiopia: food cold chain quick summary

Dimension	Barriers	Enablers
Energy infrastructure	Grid instability at cold-chain nodes; off-grid rural base; diesel back-up	~100% renewable generation mix and very low grid emission factor; abundant solar; cooling-as-a-service [14][24]
Logistics & corridor	Landlocked; dependence on the Djibouti gateway; long inland haul; air-freight cost exposure [93]	Cool Port Addis at Modjo; the Ethiopia-Djibouti railway; Ethiopian Airlines perishables terminal (~450,000 t/yr) [88][90]
Financing & affordability	Upfront capital for domestic and smallholder cold rooms; fragmented demand	Cold-chain market ≈ USD 323 m (2024) to ≈ 917 m (2033); cooling-as-a-service and development finance [32]
Regulatory & compliance	No NCAP; no MEPS for commercial refrigeration. [15]	Kigali ratified (2019); CRGE / NDC framework driving low-GWP adoption [13][15]
Market structure	~40% post-harvest losses; fragmented smallholder base; spoilage dominates emissions [31][87]	Cut-flower and horticulture exports; largest livestock population in Africa [92][85]

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