Background Documents

Cooling for All

Current and Projected Cooling Demand

MARCH 2018

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ADDRESSING DATA LIMITATIONS

Access to cooling is a new area of investigation and, inevitably, when piloting a new approach not all the data one would wish to examine is neatly lined up, especially when it comes to looking for disaggregated data on vulnerability based on gender, health, and education level.

To support this publication, an extensive data gathering exercise and literature review was undertaken, including a call for data to organizations that may have access to enhanced levels of granularity. The data expressed herein draws on a model produced by SEforALL that is based on data received through that process and data which is publicly available, and given limitations is subject to assumptions and margins of error.

In a nascent field such as access to cooling, it is crucial that organizations be empowered to put concerted efforts in the collection of a more extensive set of **granular and verified data at country level**, as well encouraging organizations with significant non- public datasets to make them available to KCEP and selected partners. This would allow for more detailed access gap quantifications with a lower error margin, in order to inform both discussions with key stakeholders as well as future policy and program design. Organizations that may have the knowledge and capacity to undertake such an effort include: GIZ, CLASP, GAVI, Global Cold Chain Alliance, the Global Food Cold Chain Council, UN Habitat, and the IEA,

CURRENT AND PROJECTED COOLING DEMAND

1. STATE OF PLAY FOR THE GLOBAL COOLING ACCESS GAP

The current cooling demand consists of both met and unmet demands ('needs') for cooling. Very few readily available data exist on the second category, the lack of access to cooling. We know that in 2016 an estimated 1.06 billion people lacked **access to electricity**. Most these populations are based in developing countries, predominantly in Sub-Saharan Africa and Asia. A large number of those dealing with energy-poverty, estimated at approx. 80%, live in rural areas, with 2016 data showing a 96% overall access rate for urban areas and a 73% rate for rural areas.[i]

In 2015 the International Energy Agency (IEA) and the World Bank identified a list of 20 high-impact countries, comprising countries with the highest absolute gaps in access to electricity and/or clean fuels and technologies for cooking, measured by population. Together they account for 80% of the people living without access to electricity. Countries on this list where at least around 40% or more of the population did not have electricity access included Angola, Bangladesh, Burkina Faso, Congo (DR), Ethiopia, India, Kenya, Korea (DPR), Madagascar, Malawi, Mozambique, Myanmar, Niger, Nigeria, the Philippines, Sudan, Tanzania, and Uganda. As an example, in Angola 69% of the urban population and only 6% of the rural population are deemed to have access to electricity, leaving 17 million people without such access.[ii]

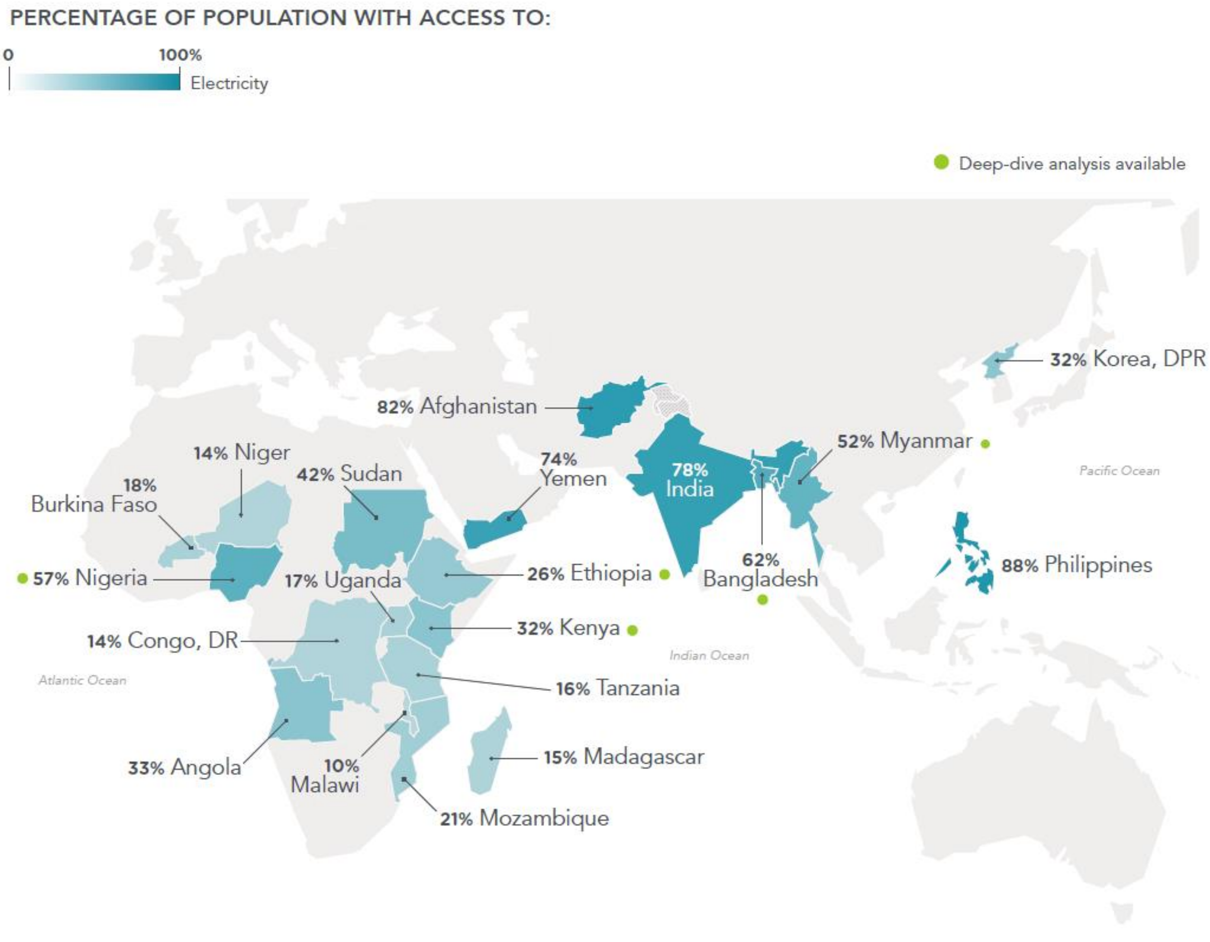


Figure 1 Access to electricity in selected African and Asian 'high impact' countries[iii]

Given current trends, more than half a billion people in sub-Saharan Africa could still be without power by 2040 due to population growth, and even those who have access to electricity can't necessarily rely on it. About another 1 billion people are estimated to have unreliable access to electricity, and in Tanzania for instance, power outages are so common that they cost businesses 15% of their annual sales.[iv]

The **lack of sufficient cooling access** - e.g. homes, work places, schools, hospitals, cold chains for food & medicines incl. transport and storage, industry, datacenters - is likely to exceed the lack of access to energy. The lack of sustainable, affordable and energy efficient cooling access is even higher. This includes those, who are likely to gain (enhanced) access to cooling in the next decades as a result of e.g. urbanization, GDP/household income increase etc, however may be locked into unsustainable cooling solutions if no further action on cooling is taken to offer them better solutions.

Unlike energy access which affects mostly rural populations, **the lack of cooling affects both urban and rural populations**. Urban residents for example may have access to electricity, but live in poorly designed buildings and urban environments that heat up quickly, while lacking the purchasing power to buy and power a cooling appliance, either for room cooling or to keep food fresh.

An example are urban residents in slums, which are often haphazardly built and designed -not in the least as many don't have secure tenure and may be evicted at any moment - and where many people live at or below the poverty line[1]. An estimated 1 billion urban dwellers currently live in slums. In Sub—Saharan Africa, as much as 59% of the urban population lives in slums, whereas about 28% of urban residents in Asia and about 21% of urban residents in Latin-America live in slum areas. Although the total urban population living in slums in developing countries decreased from 39% to 30% between 2000 and 2014, the absolute number of people living in slums continues to grow as a result of population growth, with Sub-Saharan Africa and Asia expected to have the largest slum populations by 2025.[v]

[1] Poverty line is the minimum level of income deemed adequate in a particular country. Although this depends on the cost of living for each country, in October 2015 the World Bank updated the international poverty line to US$1.90 per person a day

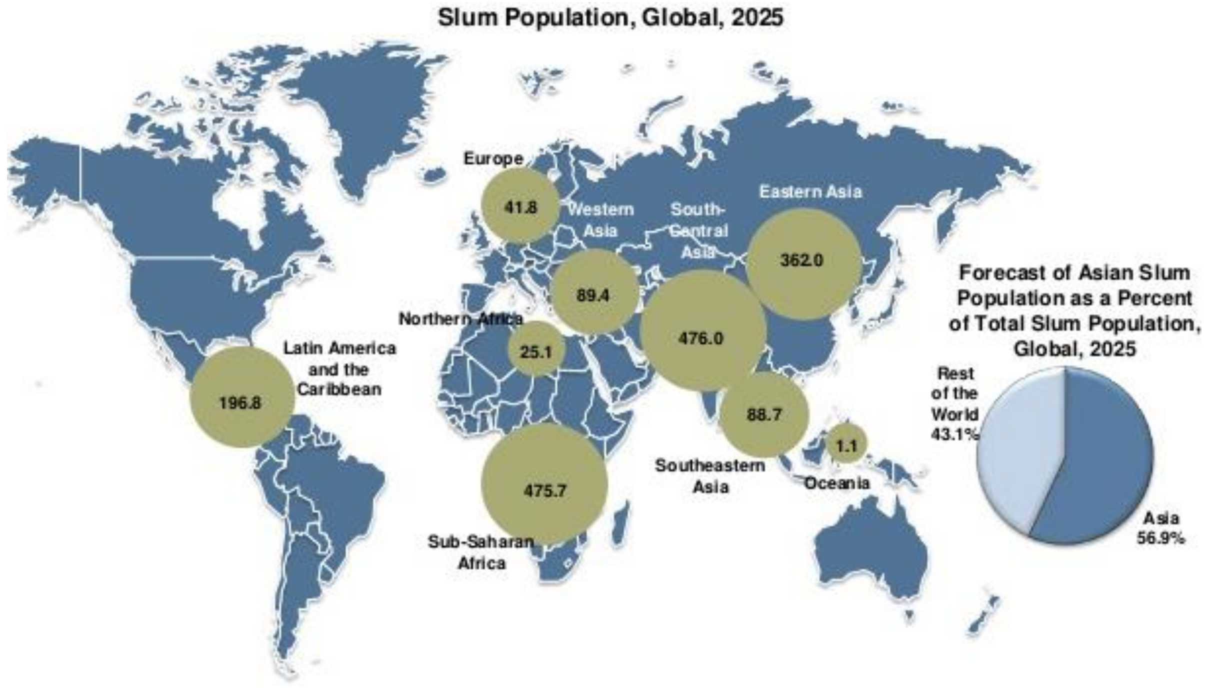


Figure 2 Estimated slum population by 2025 – the numbers represent millions of people[vi]

Extending access to cooling to countries with critical gaps in cooling access – as per the Tiers framework - can not only help deliver many socio-economic and health benefits in line with the SDGs, but also help these countries 'leapfrog' to sustainable cooling solutions that are affordable, energy efficient and have low or no global warming potential (GWP).

2. SECTORAL OUTLOOKS

Cooling demand in buildings

Surge in air conditioning energy demand

Buildings are major sources of energy *end* use, currently responsible for roughly a third of global energy consumption as well as a third of global human-induced CO_2 emissions. One of the most rapidly growing energy demands in buildings is cooling by means of **air conditioning** (AC). Air conditioner sales are growing at 10–15% per year in hot, populous countries such as Brazil, China, India and Indonesia.[vii] A typical room AC unit uses 10-20 times as much electricity as a ceiling fan. The IPCC projects that worldwide power consumption for AC alone may surge as much as 33-fold by 2100 versus current levels, to more than 10,000 TWh[2] in 2100, as developing world incomes rise and urbanization advances. This is equivalent to roughly half the world's total electricity generated in 2010.[viii] Studies from Mexico suggest that in warm regions, the rise in income levels is strongly correlated to a rise in AC use, with penetration levels reaching over 80% in areas where people can afford them.[ix]

[2] Twh refers to terawatt hours. One TWh is equivalent to one thousand billion kilowatt hours.

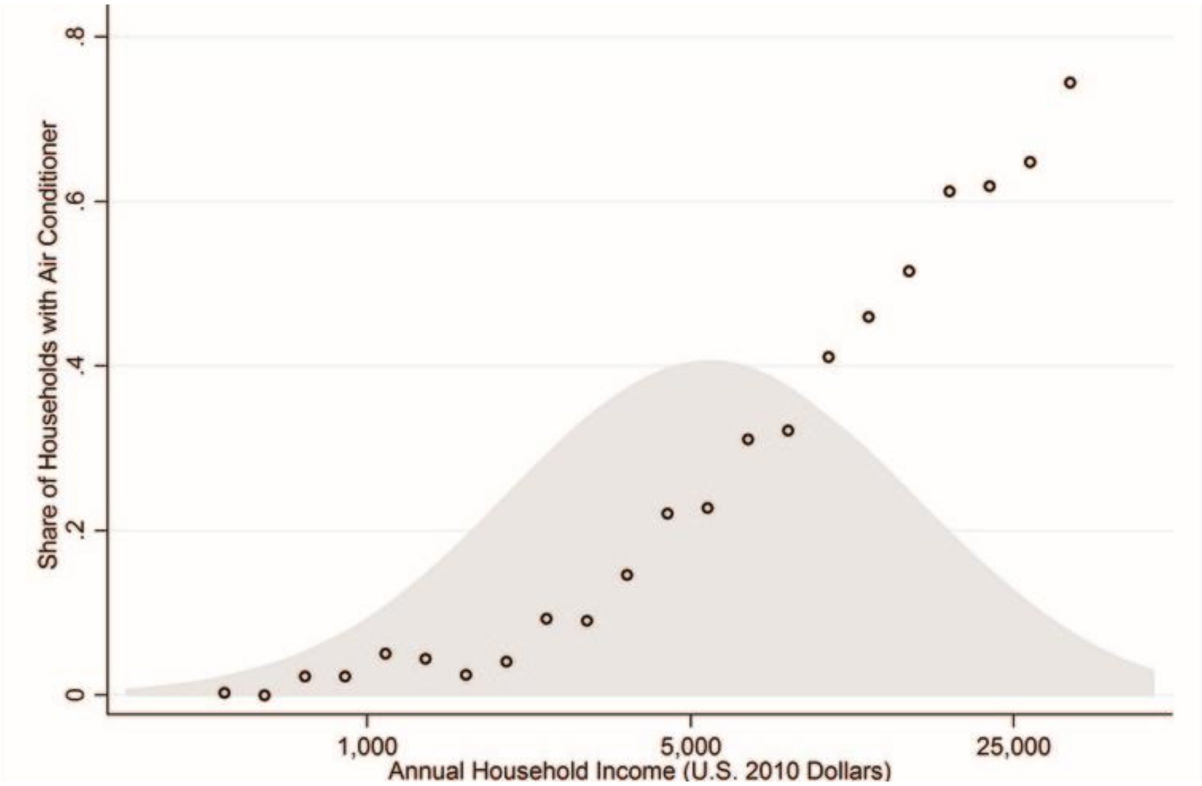


Figure 3 Relationship between annual household income and AC uptake for municipalities located in warm regions of Mexico[x]

Although the US, which has the highest AC penetration level of any country with almost 90% of households having one or more AC units[xi], is currently already using as much electricity to keep its buildings cool as the entire continent of Africa uses for all its electricity needs, countries with large populations like China and India are fast catching up.

The Lawrence Berkeley National Laboratory (LBNL) expects that India is poised for a veritable explosion in room AC use, as a result of millions of Indians crossing the income threshold that makes AC within their reach. The result would be a doubling of the country's electricity demand in the next 15 years, requiring as many as 300 new power plants just to provide for the additional AC demand, barring a significant improvement in the efficiency of AC equipment. [xii]

In China, urban dwellers have already purchased about 200 million room ACs in recent years -with 64 million AC units sold in China in the year 2013 alone[xiii]-, creating enough additional energy demand to power the equivalent of six California's.[xiv] Under current trends, an estimated 700 million AC units are expected to be installed globally up to 2030 and 1.6 billion by 2050 according to LBNL, mainly in hot, developing countries.[xv]

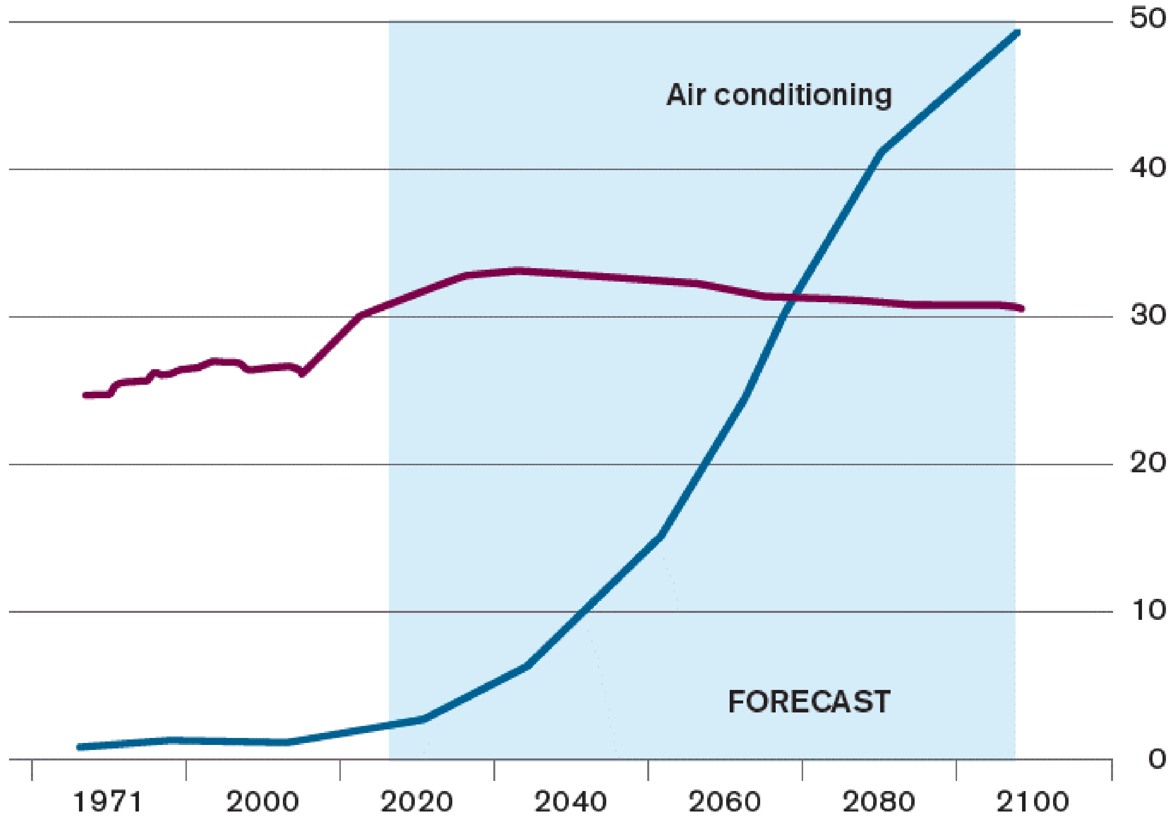


Figure 4 Worldwide forecast energy demand for space heating (purple line) and space cooling (blue line), in exajoules. [xvi]

Artificial cold is a fairly recent phenomenon though and still off-limits for hundreds of millions of lower-income people. For thousands of years before the invention of so called active cooling solutions, which require supplied energy such as electricity or gas to operate, people lived successfully in warm and hot climates by using passive cooling solutions. And for many people in both developed but to a greater extent in developing countries, this is still the only or main form of building cooling provision they have.

Passive cooling focuses on heat gain control and heat dissipation in a building through measures that require very low or no energy consumption, either by preventing heat from entering the interior (heat gain prevention) or by removing heat from the building (natural cooling). These solutions by their very nature do not use any F-gases to operate, neither put a demand on available energy supplies. Many ancient techniques can still be found applied in building designs around the world.

Over the past half to whole century however, cities have increasingly taken on unstable thermodynamic forms. Turn off the AC, if there is any, and many of these modern buildings become almost uninhabitable during periods of warm to hot weather. Movements such as rapid population growth coupled with urbanization, an increase in building density, insufficiently stringent building regulations, and 'modern' building design (like the high-rise office block with deep, cheap-to-build interior spaces) which relies heavily on active cooling solutions such as AC, have all contributed to this trend. Cooling technology or simply the hunger for profit by maximizing buildable area for low-income housing on a plot of land, have increasingly resulted in building designers and developers foregoing relatively expensive hot-weather building design features such as large eaves, high ceilings, and cross-ventilated designs, or even simply installing windows that open and attic fans.[xvii]

While this has resulted in many city dwellers in developing and emerging countries now living in cramped high-density 'hot boxes', those who can afford it often buy active cooling solutions such as ACs as soon as their income level allows in order to mitigate the situation. Ironically, the **surge in the use of AC** units for cooling of buildings can actually **increase temperatures in cities**, with the effects particularly noticeable at night.

Scientists from Arizona State University in Phoenix, USA, demonstrated in 2014 that the widespread use of AC in hot and dry cities such as Phoenix causes local heating of urban atmospheres, resulting in a 1-2°C temperature increase at night time – and suggesting that the waste heat from ACs could be put to better use if captured and turned into useful energy, such as for water heaters.[xviii] The Royal Meteorological Society had already come to a similar conclusion in 2012 for the city of Paris, if the city were to significantly increase its AC use.[xix]

In the city of Ahmedabad, India, a city of 5.5 million residents, this same phenomenon has health officials concerned that with all the new ACs being installed and subsequently pumping heat out into the streets, **temperatures** will be further **raised inside the homes of those who can't afford an AC of their own**. Every summer the city bakes, with the summer of 2015 seeing temperatures as high as 45°C, until the monsoon comes which has temperatures drop into the 30s°C range although with humidity rising to stifling levels.

ACs now already account for up to 60% of summertime electricity use in Indian cities like New Delhi, and rather than merely a luxury good, having an AC -or not- can now mean the difference between life and death in India's increasingly hot climate, where heat waves which kill more than a hundred people have become more than twice as likely since the 1960s.[xx] In fact, a new study in Nature predicts that by the end of the century, under a best-case scenario almost half of the world's inhabitants will face deadly heat and humidity for more than 20 days a year.[xxi]

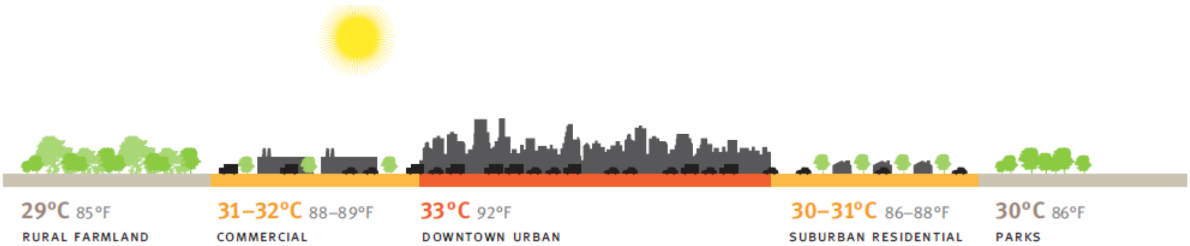
Cooling access for low-income urban dwellers
Next consider the percentage of **urban population living in slums.** Due to the slums informal nature including the lack of secure land tenure and with slums frequently being ignored by municipal government, these residents are more likely to live in poorly designed buildings, not suited to cope with heat. Even though they may have a certain degree of access to electricity, potentially informally - for example by tapping nearby wires -, they may not have the purchasing power to buy and run a cooling device or simply have access to a safe, good quality and reliable power supply. In the 15 countries with the largest percentage of its urban residents living in slums, all of them located in Sub-Saharan Africa with the exception of Haiti, between 70 to 96% of urban residents live in slum areas, therewith unlikely to have the cooling access they need to maintain thermal comfort in their homes when the heat strikes.[xxii]

In 2016, the UN named Orangi Town in Karachi, Pakistan, as the largest slum in the world with an estimated 2.4 million residents. The area is known for large-scale illegal tapping of electricity, which according to the local utility is beyond lost revenue also a major cause of electricity faults and tripping. Although many of its inhabitants now do have a legal connection the electricity grid – in part due to the utility's drive to install 'anti-theft cables', they still face regular power outages, not in the least because of a practice known as load shedding[3]. A 2015 heat wave, which had temperatures soaring to 45ºC, in combination with power blackouts of up to 12 to 14 hours a day in places like Orangi Town, led to many avoidable heat-stress deaths, the majority occurring in the slums.

With buildings forming the fabric of rapidly growing urban landscapes, while the top 30 of hottest cities in the world can all be found in developing and emerging countries, pathways of transformative change for cooling will have to be enacted if both the SDGs and the Paris Agreement's vision of a decarbonized world are to be achieved.

Cooling demand in cities

Urbanization and the urban heat island effect
Urbanization in combination with population growth is projected to add an estimated 1.5 billion more people to the world's urban population by 2030, resulting in **6 out of 10 people worldwide living in cities**. An extra 1 billion people will be living in cities by 2050, with close to 90% of this increase concentrated in Asia and Africa[xxiii]. Already more than 3 billion people living in the tropics and subtropics, with the top 30 of hottest cities in the world all found in developing and emerging



countries, which also host the majority of the world's megacities.

Figure 5 Depiction of the Urban Heat Island Effect[xxiv]

Many existing large cities will sprawl – with each of the top ten largest cities in the world in 2030 expected to have more than 22 million inhabitants – and entirely new ones will be built. Megacities such as Beijing, Delhi and Mumbai already have extremely high levels of air pollution, which can be exacerbated by hot weather. The probability of smog for instance increases by 6% per 1°C temperature increase at ambient air temperatures over 22°C.[xxv] Many cities will also considerably expand their supply of building stock and urban infrastructure in the next decades, either through greenfield or brownfield[4] developments.[xxvi] This means we have a valuable but limited 'window of opportunity' to design these urban environments, such that they're optimized to deal with a warming world - or instead lock cities into unsustainable building cooling pathways.

Currently a large number of cities experience the so called '**urban heat island effect'**[5], which is primarily caused by the replacement of natural surfaces with hard impervious (asphalt and concrete) surfaces such as roads and other paved areas, and roof tops, which are all relatively dark and absorb large amounts of solar radiation.[xxvii] In rural areas, vegetation and a more open land form typically dominate the landscape. As cities develop, often a considerable amount of vegetation cover is lost,

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[3] Load shedding refers to the deliberate shutdown of electric power in a part or parts of a power-distribution system, generally to prevent the failure of the entire system when the demand strains the capacity of the system
[4] Greenfield land is undeveloped land in a city or rural area either used for agriculture, landscape design, or left to evolve naturally. Greenfield developments therefore have no existing (infra)structures in place; brownfield developments on the opposite take place in areas that have been previously used for other urban purposes
[5] Urban Heat Island (UHI) effect is the term given to localized higher temperatures that are experienced in urban environments compared with the temperatures of surrounding green spaces

and surfaces tend to become paved or covered by buildings and other infrastructures instead. Trees and other vegetation however provide valuable shade, which helps to lower surface temperatures, while through a process called evapotranspiration[6] they also help reduce air temperatures. In contrast, urban areas are often characterized by dry, impervious surfaces not able to provide similar cooling services. [xxviii]

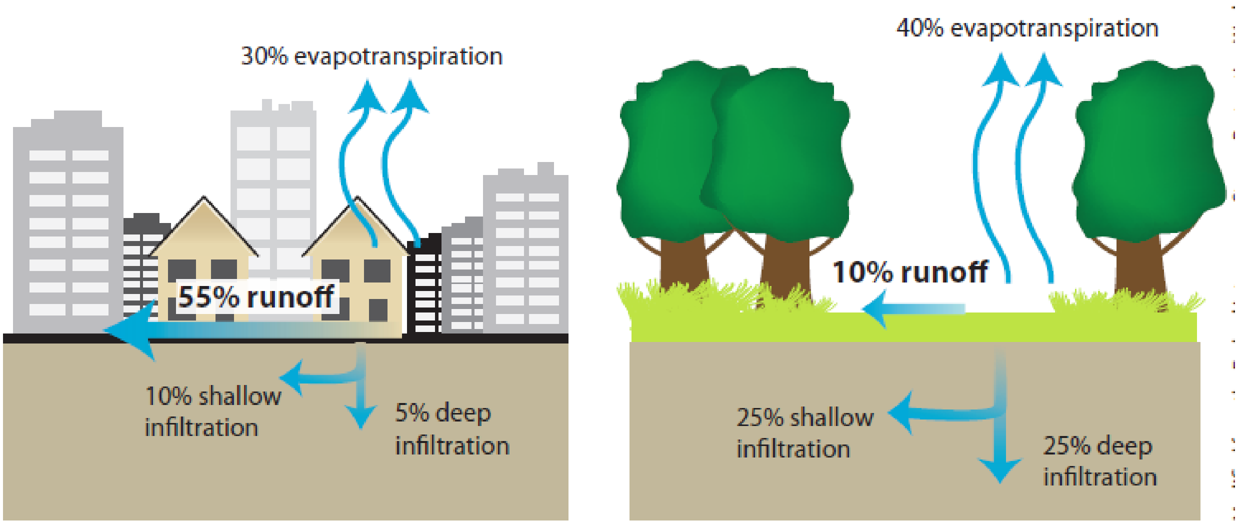

Figure 6 Impervious surfaces and reduced evapotranspiration [xxix]

Artificial urban surfaces typically have relatively low albedo values (the fraction of incoming solar radiation reflected back into space) and high thermal conductivities, therewith absorbing and re-radiating up to 90% of the total incoming solar radiation.[xxx] An additional factor is the urban geometry, which influences wind flow, energy absorption, and a surface's ability to emit long-wave radiation back to space without being obstructed by other objects, such as neighboring buildings. Together this can result in **an increase in temperatures** for a city with one million or more inhabitants **of as much as 4-7ºC** in comparison with adjacent vegetated areas,[xxxi] and on a clear, calm night, this temperature difference can even be as much as 12°C. Smaller cities and towns can also be prone to heat islands, though the temperature effect usually decreases, the smaller the city's size.[xxxii]

Indian government-backed research in both Delhi and Mumbai has now shown that both cities have become urban heat islands, with significantly higher temperatures to nearby rural areas. Delhi and Mumbai have more than doubled in size and population in the past 25 years as rural migrants have flooded in. Temperatures in both cities have risen 2-3ºC in only 15 years, while the cities are 5-7ºC warmer than the surrounding rural areas on summer nights.[xxxiii]

Urban heat islands can also aid in the **transmission of certain diseases**. In Sao Paulo, Brazil, for instance researched found that attributes of the urban heat island such as higher surface temperatures, lower humidity, and poor vegetation cover, favored the transmission of mosquito-borne dengue fever. A majority of dengue cases occurred in parts of the city with areas with temperatures over 28ºC, and in particular in areas with temperatures over 32ºC. The dengue incidence rate was almost 33 times as high in areas with low vegetation cover versus areas with high vegetation cover at a surface temperature of 29 ± 2ºC.[xxxiv]

The urban heat island effect is further aggravated by conventional cooling technologies, such as air conditioning, which expel heat into their immediate surroundings, therewith forcing themselves and

[6] Evapotranspiration is a process in which plants release water to the surrounding air, dissipating ambient heat

other cooling systems to work harder.[xxxv] Not only buildings are increasingly equipped with air conditioners, but vehicles as well with an estimated 6% annual growth in vehicle AC uptake, the use of which can add as much as 20% to a vehicle's total fuel use. Steadily increasing urban temperatures over the last decades mean that an estimated 5 to 10% of a large city's demand for electricity is now used to compensate for the urban heat island effect.

Increased daytime surface temperatures, reduced natural nighttime cooling, and higher air pollution levels all associated with urban heat islands can affect human health, while they can also exacerbate the impact of heat waves.[xxxvi] Moreover, for the worst-off cities, gross domestic product (GDP) losses as a result of intensifying urban heat islands, could add up to almost 11% by 2100, while the accumulated impacts from global and local warming for cities could be about 2.6 times as high than if they would not have urban heat islands.[xxxvii]

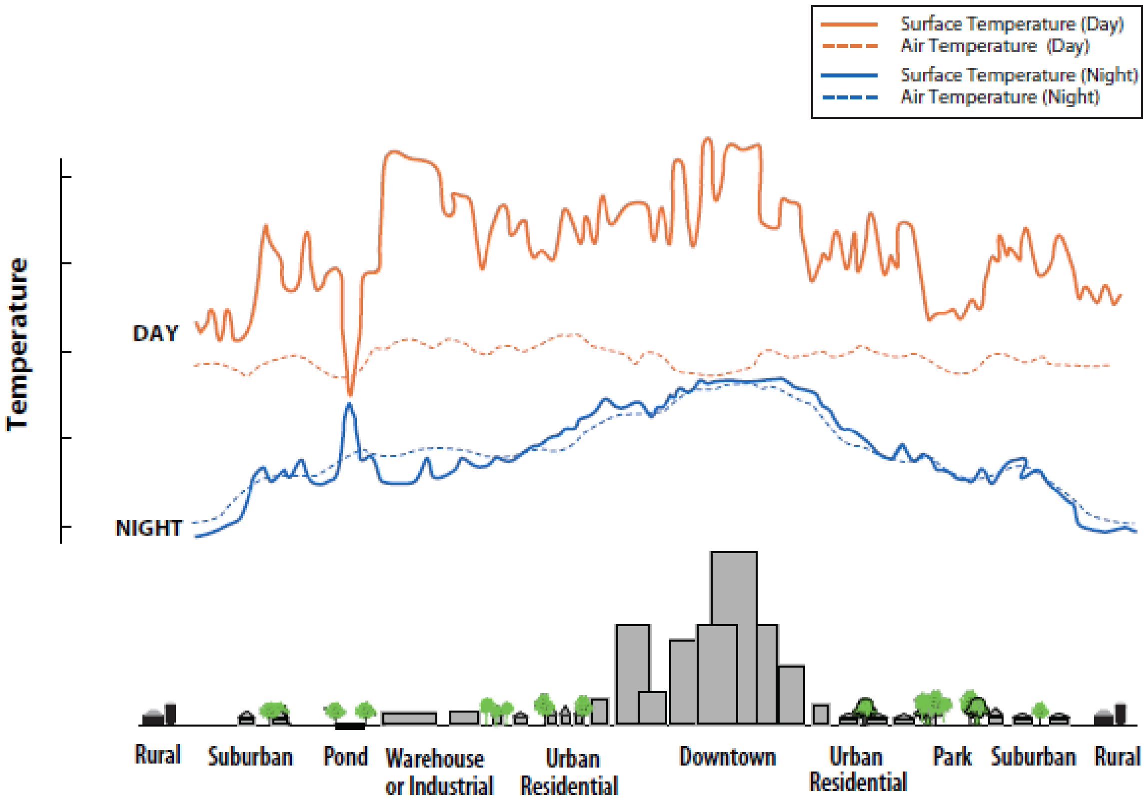

Figure 7 Variations of surface and atmospheric temperatures across the (urban) landscape [xxxviii]

As cities become warmer, they also become more deadly. A major heat wave in Europe in summer 2003 showed that **microclimate** - that is, the temperature of particular neighborhoods - was a strong predictor of death rates. Each 1°C increase in temperature raised the odds of death during this particular heat wave by 21%. Other global studies have constructed curves that relate overall all-cause mortality to the excess temperature above a safe baseline, with each 1° C increase being associated with a 3 to 5.5% increase in all-cause mortality and a 1.1 to 2.6% increase in cardiovascular mortality.[xxxix]

Occurrence of deadly heat

A 2015 study predicts that urban India will see at least a doubling of heat-related deaths before the end of the century, based on summer temperature increases of up to 3°C. In fact, in the past 50 years, **heat waves** killing more than a hundred people have become twice as likely to occur during India's hot summers. During a heatwave in the summer of 2010, in Ahmedabad, India, the number of deaths tripled to 300 a day with no other obvious reason found than the high temperatures, reaching beyond 45°C.[xl]

Other studies on **heat stress deaths** found that deaths in respectively the city of Seoul, South Korea, and Sao Paulo, Brazil increased by around 8% on heatwave days. Particularly older people and those with little education were at risk. [xli] Mortality from heat is highly episodic, and is concentrated in particular heat events. Even so, heat waves are already the weather-related disaster which causes the most mortality globally, killing an estimated 12,000 people on average annually. The World Health Organization forecasts that by 2050, deaths from heat waves could reach 260,000 annually, unless cities adapt to the threat.

Even more so, a new study predicts that by the end of this century, if carbon emissions continue on their current trajectory, three-quarters of humanity will face deadly heat. The capital city of Lagos, Nigeria, for example, could have temperatures at 40ºC or over a 100 times more often than current, while based on current projections, its population would have grown 11 times as large as it was in 1995.[xlii] Densely populated regions in the Persian Gulf, Bangladesh, and northeast India may even become so hot and humid that, they pass the "upper limit on human survivability," deadly to anyone who ventures outside for more than a few hours.[xliii]

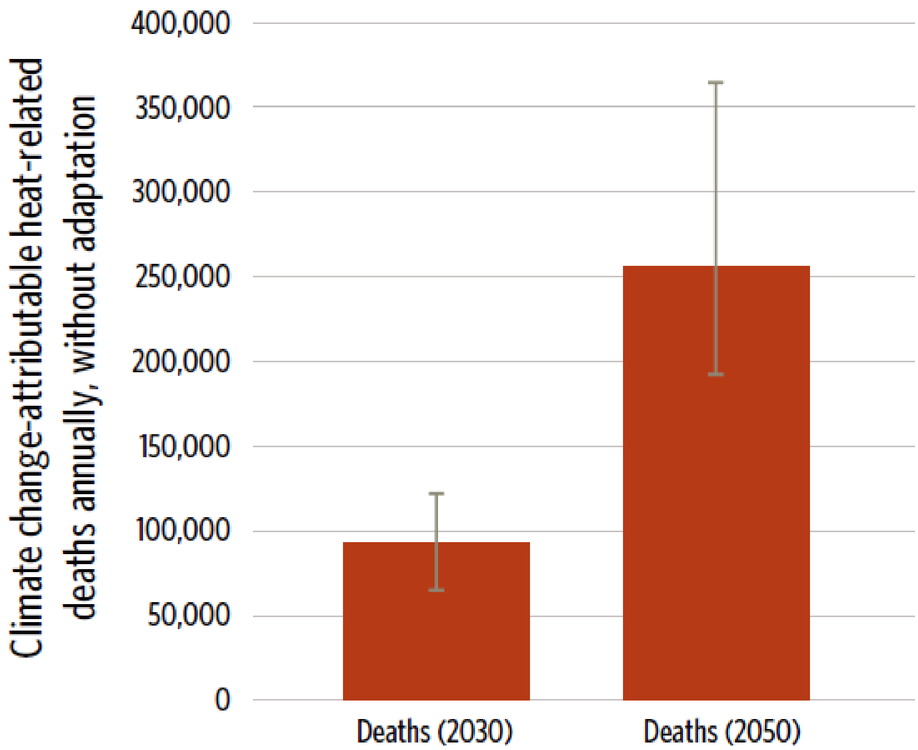

Figure 8 Forecast of climate change's impact on deaths due to excess heat, expressed as annual mortality numbers [xliv]

Heat impact on outdoor labor productivity
High heat exposure doesn't only result in higher mortality and illness rates, but also **reduces productivity**. For outdoor, in-sun work environments in South-East Asia, modelled "work capacity losses" during hot weather by 2050 for moderate work in the shade at the height of the day are

expected to be as high as 40-50%, increasing to 60-70% in the sun. Although morning and evening hours are somewhat cooler, the daily work capacity for such professions could be substantially reduced as a result of climate change.

Overall by 2050, **work hour losses by country** are expected to be more than 2% for ten world regions, going as high as 12% in the worst effected regions of South Asia and West Africa, potentially leading to economic losses worth many billions of US dollars. For severely impacted countries, this could result in a loss as much as 6% of their annual GDP/capita. Even a 2% per capita loss per year would mean that over 30 years the gains in GDP/capita for that country will have been less than half as much as if the productivity loss due to excessive heat had not occurred.[xlv]

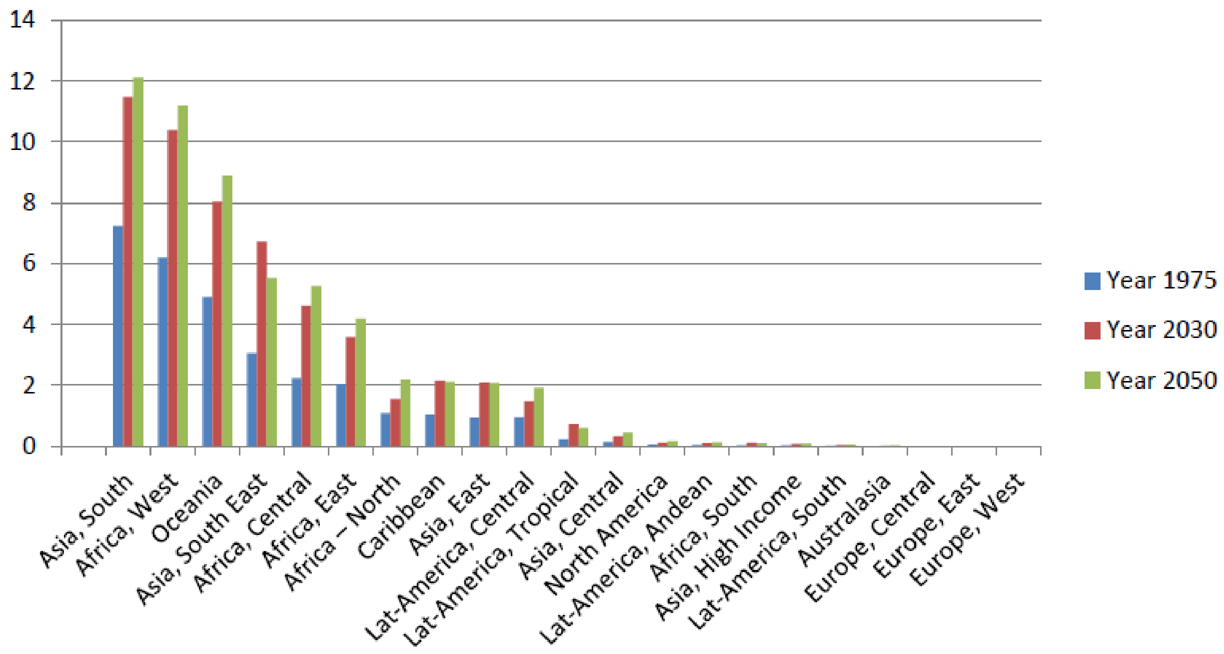

Figure 9 Estimates of percentage of annual daylight work hours lost due to excessive heat in 21 global regions in 30-year periods for 1975, 2030 and 2050 (ranked by losses in 2050), adjusted for estimated population and workforce distribution changes[xlvi]

Cooling demand in cold chains

Food loss and wastage

A cold chain is a temperature-controlled supply chain and can refer to the value chain for fresh tropical produce (at 12 to 18°C), chilled fresh produce and food products (at 0 to 4°C), and frozen food products (at -18°C). A major driver in developing countries for the growth of cold chains is a need to reduce high levels of **food loss and wastage**[7], with an estimated half of perishable food being lost before even reaching the market, largely due to the absence of proper cooling. Furthermore, in developing and emerging economies, factors such as an increase in disposable income, urbanization, changes in diet, and a demand for enhanced food services such as convenience food and home delivery, are expected to help drive considerable growth in cold chain demand.

[7] Food loss and waste hereby refer to food that either spills, spoils, or incurs an abnormal reduction in quality, or otherwise gets lost before it reaches the consumer (loss), or food that is of good quality and fit for consumption, but does not get consumed because it is discarded—either before or after it is left to spoil (waste).

b

Globally it is estimated that 1.3 billion tonnes of food, representing a third of the total food production for human consumption, is lost or wasted every year - this while more than 800 million people globally are malnourished. This results in combined **economic losses roughly equating to US$750 billion a year**, of which US$4.5 billion occurs in India annually. In India for instance, a lack of refrigerated transport means just 4% of fresh produce is transported in refrigerated vehicles compared to more than 90% in the UK.[xlvii] Meanwhile demand for food is projected to grow by 40% by 2030, with according to current trends India only being able to meet 59% of its total food demand through domestic food production.[xlviii]

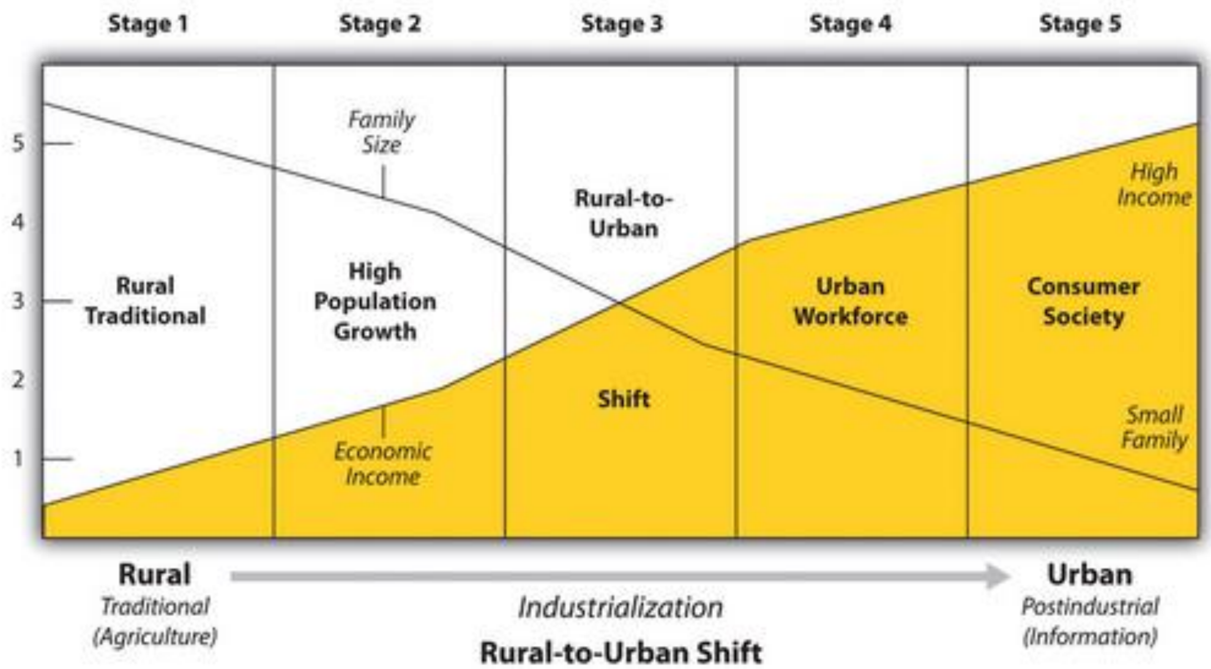

Figure 10 Pattern of growth in cold chain demand

Food loss and wastage both depresses farmers' incomes and raises food prices, resulting in an average 15% lower incomes for 470 million smallholder farmers, many of which are also counted as among the part of the world population being food insecure. Asia and Africa together account for two thirds of global food wastage, losing the equivalent of 400 to nearly 600 calories per person per day.[xlix] In developing countries however, as much as 90% of food waste – made up for 92% by crop foods and dairy - occurs in the supply chain rather than at consumer. Increasing the volume of food that arrives at consumers in good condition can therewith help raise farmers' incomes, as well as conserve precious farming resources including land and water.

Add to this that studies point towards **consumers in low income countries spending 40-50% of their incremental income on food**, which means food loss and wastage, or the reduction thereof, directly **affects poverty of the consumer base** through its impact on food prices and could potentially help alleviate undernourishment. Additional availability of fresh fruits and vegetables may also help decrease nutritional deficiencies, which affects 180 million children worldwide and can lower lifetime earnings by up to 22%. Malnutrition is the largest single contributor to disease in the world, according to the UN's Standing Committee on Nutrition, while **more children die each year from malnutrition than from AIDS, malaria and tuberculosis combined**.[l]

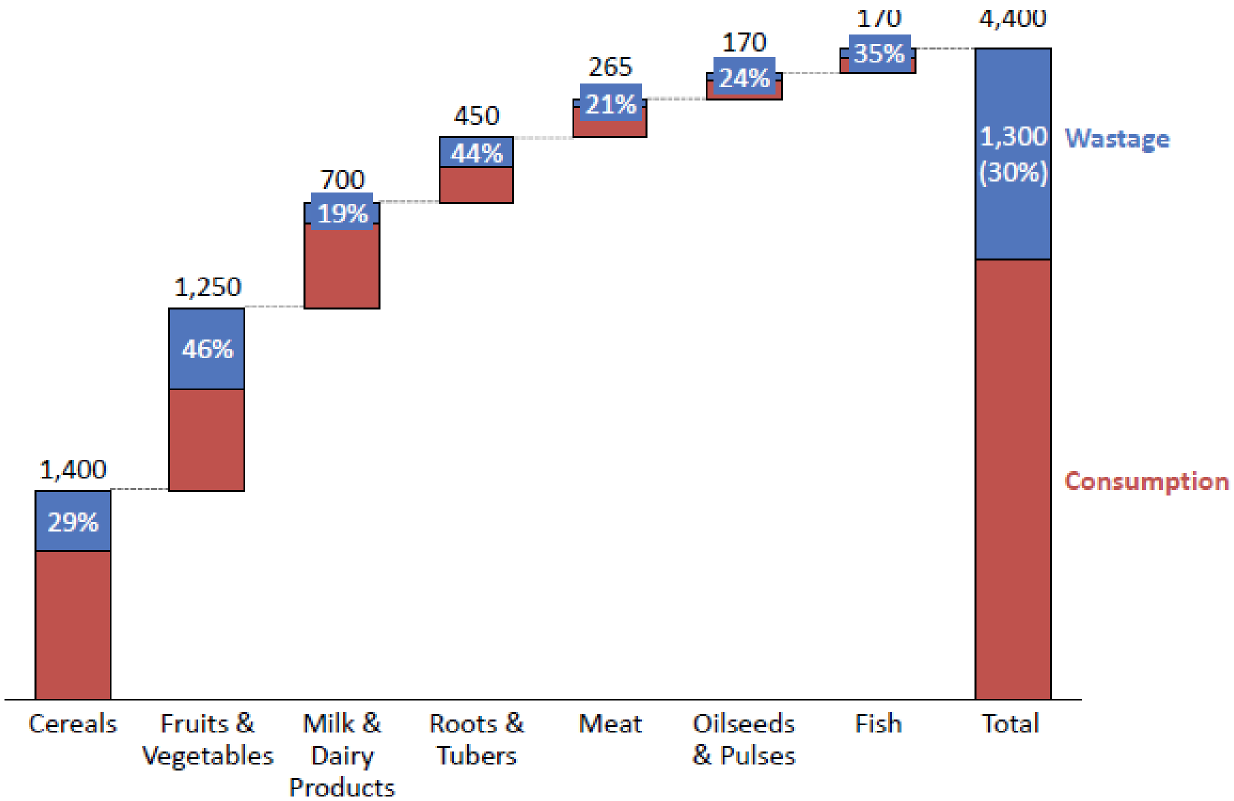

Figure 11 Global food production for human consumption, as well as consumption and wastage, by food category (in million metric tonnes and as percentage of total) [li]

Although food loss and wastage is unlikely to go away, reducing it to the lowest levels achieved in any region at each stage of the supply chain could reduce global food waste by 50% if replicated worldwide. This could feed an additional 1 billion people, probably halving the expected 60% required increase in global food production to feed an additional 2 billion inhabitants by 2050.[lii]

Reducing spoilage also helps reduce food poisoning. Every year, an estimated 600 million people fall ill and 420,000 die due to food poisoning caused by poor refrigeration or inefficient cold chains. Children under 5 years of age carry 40% of the foodborne disease burden, with about 125 000 deaths every year.[liii] Add to this that growth in the agricultural sector in Sub-Saharan Africa is considered about 11 times more effective at reducing poverty than growth in other sectors, and there should be a strong case for investing in solutions to reduce post-harvest losses.[liv] Notwithstanding this, only a very small amount of ODA funding towards enhancing agricultural productivity is being directed towards food loss and wastage. [lv]

Level of refrigeration equipment

If developing countries however had a **level of refrigeration equipment** similar to those of the developed world, 200 million tonnes or roughly a quarter per annum globally of perishable food that currently goes to waste could be saved, expanding the available food supply by about 14%. India for instance has an estimated 10,000 refrigerated vehicles serving a population of 1.3 billion people, whereas France has 140,000 of such vehicles for a population of just 66 million.[lvi] In a country such as the Democratic Republic of Congo with a tropical climate, only 3.65 million domestic refrigeration appliances are available to a population of over 73 million people, compared to a country like Germany with a temperate climate and over 82 million people who have 43.3 million domestic refrigeration appliances available to them meaning pretty much every household has a fridge and/or freezer.[lvii]

A better cold chain would also help **conserve large quantities of farm inputs** currently used to produce food that does not end up being consumed. Food wastage also contributes large quantities of CO_2 emissions. If food wastage would be a country, it would even be the third biggest global emitter of CO_2 emissions after the USA and China. [lviii]

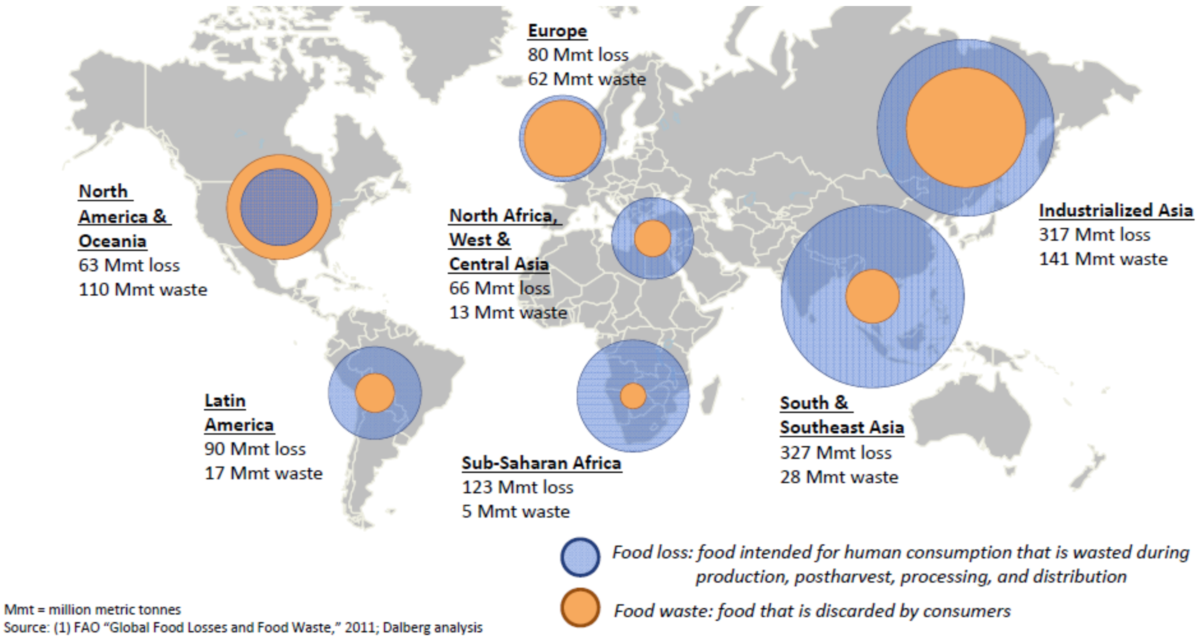

Figure 12 Over 90% of food loss and wastage in developing Asia and Africa occurs pre-consumer[lix]

At the same time if countries, such as India, China, Brazil, Indonesia, and Mexico, which currently have a relatively low level of installed cold storage capacity (Figure 13), would increase their cold storage to the level of provision in the USA, a significant increase of their energy use for cold storage could be expected if similar, conventional technologies were to be applied. Going back to the comparison in domestic refrigeration appliances between the Democratic Republic of Congo, where 70% of people live below the global poverty line, and Germany, a relatively wealthy country and known as a champion for green growth, the per capita CO_2emissions from energy use and 'F gas' leakage combined for domestic fridges and freezers stood at 0.63 kg per capita in Congo and at 104 kg per capita in Germany, 165 times higher.

Also, if we consider the current **environmental impact** of the approximately 1 million refrigerated vehicles on the road in Europe, emitting around 13 million tonnes of CO_2-e annually, as well as NOx and PM emissions equivalent to respectively over 26 million and 56 million Euro 6 diesel cars[8], significant emissions are likely to occur from a rapid increase in refrigerated vehicles in developing

[8] NOx and PM refer to respectively nitrogen and particular matter air emissions. Conventional diesel-powered transport refrigeration units (TRUs) emit up to 6 times more NOx and 29 times more PM than the diesel propulsion engine pulling then around. Euro 6 refers to an European emission standard for NOx and other air pollutants and all new cars sold in Europe must meet the Euro 6 standard.

and emerging countries if no strides were to be made to alter the technology and energy source – for example by using liquid air or liquid nitrogen instead - for cooling these vehicles. [lx]

These data exemplify that it is critical to not only focus on expanding access to refrigeration such that the world's poor populations can start to reap the many benefits of such access, but also to focus on **how to avoid and leapfrog the high emission refrigeration pathways that industrialized countries have taken**. [lxi] Notwithstanding this, 2016 research by the Global Food Cold Chain Council suggests that the increase in carbon emissions from expanding cold chains for perishable foods in developing countries through the use of relatively energy inefficient cooling technologies is a factor 10 lower than the decrease in emissions resulting from the reduction of food waste, the latter which come with many other SDG benefits – not taking into account potential rebound effect.[lxii]

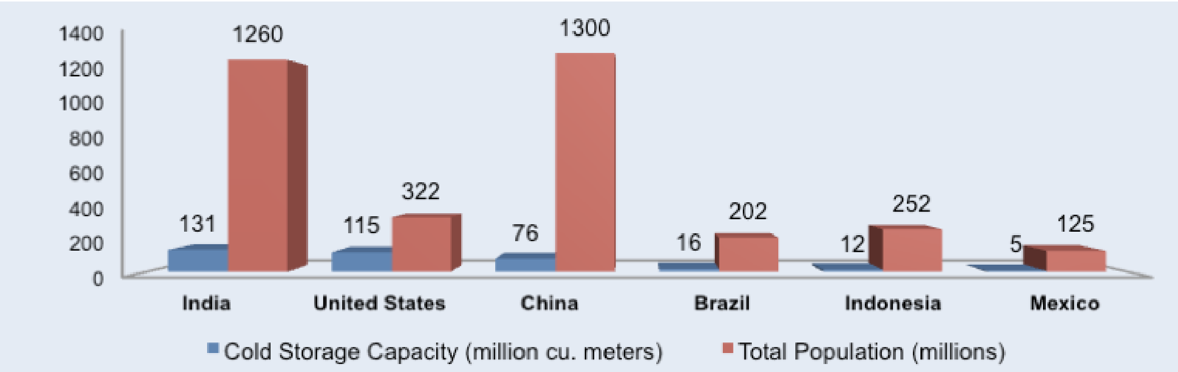

Figure 13 Population versus installed cold storage capacity for a select number of countries[lxiii]

Vaccine distribution

The lack of a (continuous) cold chain also hampers the effective **distribution of vaccines** – access to which could prevent more than two million deaths from diseases a year in developing countries. In 2013 the global vaccine market was worth approximately US$24 billion in 2013 with the large majority of vaccines requiring a cold chain to remain viable. The World Health Organization (WHO) estimates that nearly 50% of freeze-dried and 25% of liquid vaccines are wasted each year, with disruption in the cold chain as one of the largest contributors to this wastage.

How important vaccines can be for our well-being is exemplified by the role of refrigeration in the eradication of polio. In 2013, the number of cases of polio occurring worldwide stood at 416, compared to 350,000 cases registered in 1988, 25 years earlier.[lxiv]

India as the world's third largest pharmaceutical producer is plagued by inadequate cold logistics. An estimated nearly 20% of temperature-sensitive healthcare products in India arrive damaged or degraded, because of broken or insufficient cold chains, including a quarter of vaccines. Temperature-sensitive medicines, that need to be kept at a temperature between 2 and 8ºC, experience considerable market expansion around the world however, with turnover increasing by as much as 20% per year. While these medications represent only 2% of the total volume of medicines, their value approaches 15%.

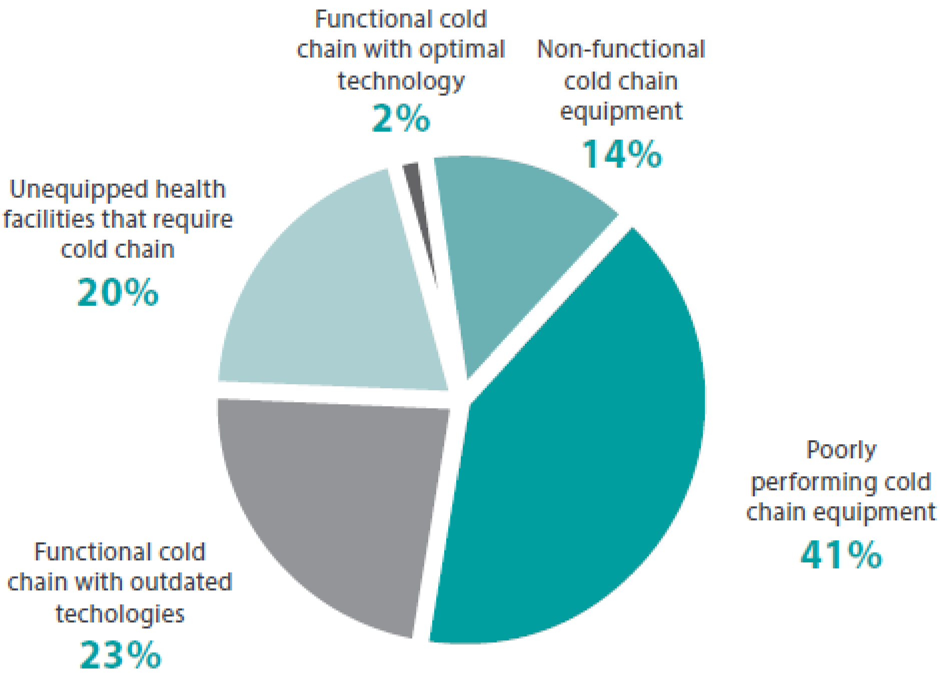

Figure 14 Cold chain equipment status (2014) for the vaccine supply chain in low- and lower-middle-income countries[lxv]

In particular the lack of grid electricity is a major threat to the continuity of the medical cold chain. The

main conventional alternatives to electrically powered refrigerators - kerosene- and gas-driven refrigerators - are plagued by problems with gas supply interruptions, low efficiency, poor temperature control, and frequent maintenance needs. As a result, there are currently no kerosene- or gas-driven refrigerators which qualify under the minimum standards established by the World Health Organization's Performance, Quality, and Safety (PQS) system.[lxvi]

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