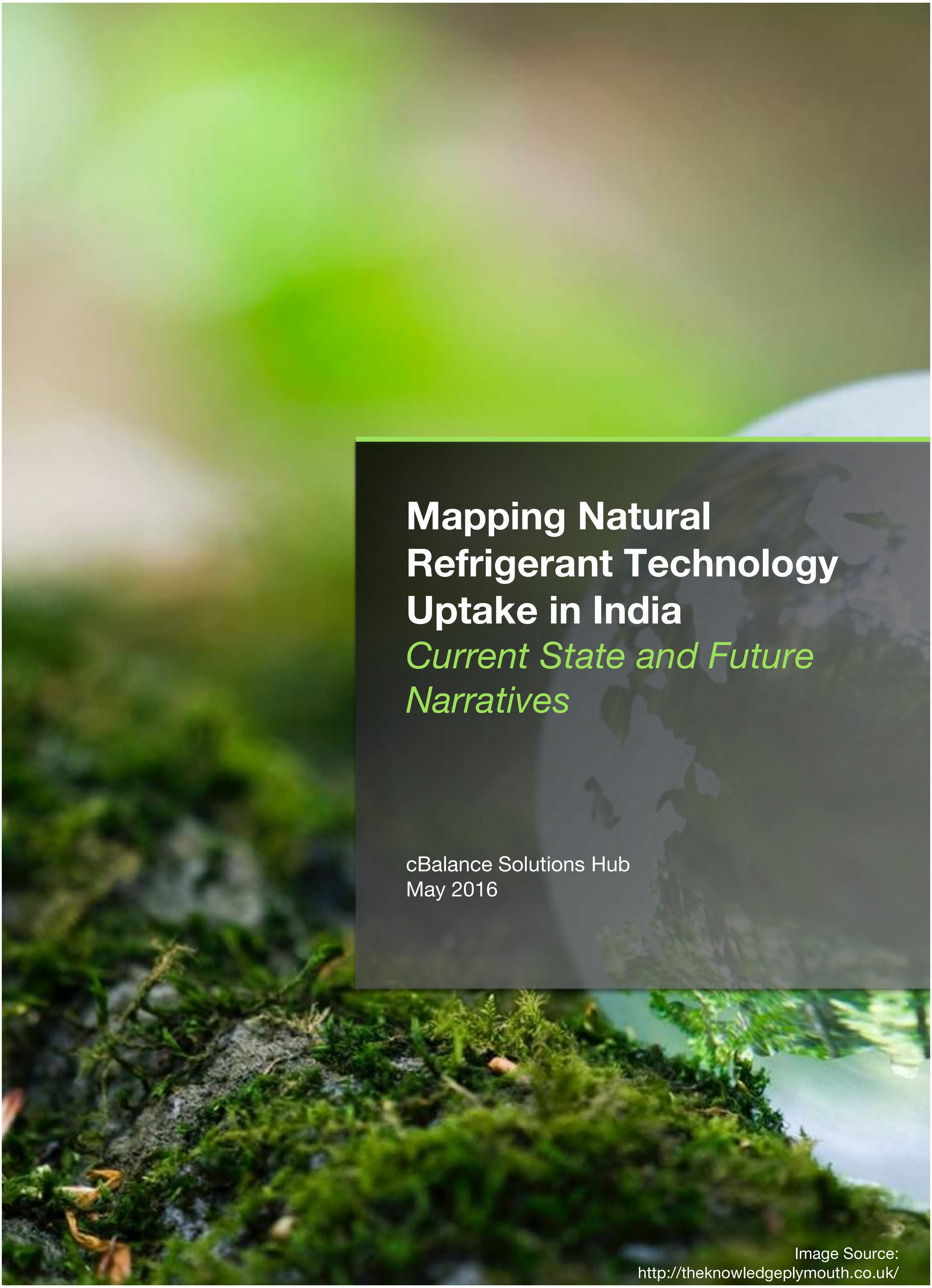


Mapping Natural Refrigerant Technology Uptake in India

Current State and Future Narratives

cBalance Solutions Hub
May 2016

Image Source:
http://theknowledgeplymouth.co.uk/

Mapping Natural Refrigerant Technology Uptake in India: Current State and Future Narratives

Analysing current usage and potential for future uptake of Natural Refrigerants across India

cBalance Solutions Hub
May 2016

CBALANCE

carbon ▸ cost ▸ community ▸ climate

CONTENTS

LIST OF FIGURES

LIST OF TABLES:

01

1 Background: Refrigerant Alternatives in India

Amidst the pressing undertaking by governments across the globe to drastically reduce greenhouse gas (GHG) emissions towards prevention of catastrophic climate change, some exceptionally potent greenhouse gases have been unfortunately ignored. While the importance and action plans towards reducing greenhouse gas emissions focus primarily on commonly known GHGs such as Carbon Dioxide (CO_2), Methane (CH_4), and Nitrous Oxide (N_20), emissions from other highly potent GHGs, if left unchecked, would perhaps lead to an inevitable failure in combating climate change.

These extremely potent GHGs are in fact man-made fluorinated gases, commonly known as F-gases, used primarily for Refrigeration and Air-conditioning purposes. It is a well-established fact that these F-gases are thousands of times more potent GHGs than CO_2. By the year 2005, these F-gases were already responsible for 17% of impact arising from climate change (IPCC, 2007). While the first generation of F-gases, the ChloroFluoroCarbons (CFCs) were banned under the Montreal protocol, owing to their ozone depletion properties, the alternative, developed by the chemical industry, commonly known as HydroChloroFluoroCarbons (HCFCs) in a bid to save the ozone layer also led to an overwhelming impact on climate change. These too are now being banned under the Montreal Protocol (Carbajal. P et al, 2009).

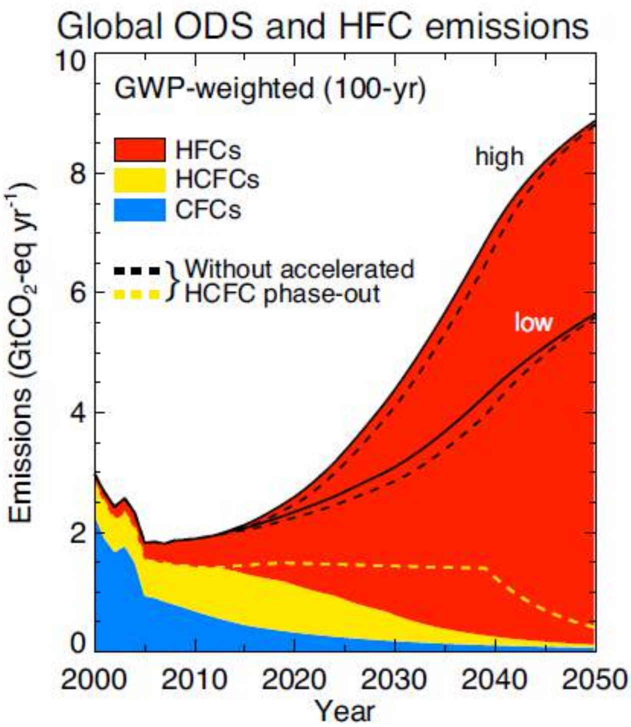
In an attempt to replace HCFCs, focus has already shifted towards the third generation of F-gases. HydroFluoroCarbons (HFCs), a stop-gap solution to the issue, are again powerful GHGs developed to avoid ozone depletion. HFCs are already being used as substitutes and if their growth is unchecked, they are likely to overtake emissions from CFCs and HCFCs by as early as 2025 and further intensify by 2050 (*See Figure 1*). Moreover, the demand for HFCs in developing countries or refrigerants has seen a steady growth of 20% between 1989 and 2007. This growth is only expected to grow further (Velders et al, 2009). If estimates are to be believed, consumption of HFCs in developing nations would be 8 times greater than in developed countries by 2050, translating into a global consumption of 3.5 times higher than peak consumption of CFCs and HCFCs in 1989 (Velders et al, 2009) (*See Figure 3*).

Additionally, according to recent peer reviewed reports, global HFC emissions in 2050 would be 9% to 19% of the total projected CO2 emissions globally in BAU scenario i.e. under no adoption of CO2 Stabilization scenario. This would give rise to GWP weighted HFC emission to increase from 5.5-8.8 GtCO2e per year by 2050. But this percentage would increase from 28% to 45% of projected global CO2 emission in 450 ppm CO2 Stabilization scenario. (Velders et al, 2009). In fact, ever since the implementation of UNFCCC's Kyoto Protocol, HFC emissions have increased by 15% every year (UNEP, 2009).

The world is currently at a crossroad, wherein we could either opt for HFCs and let its growth go unchecked to a point of no return and cause catastrophic climate change or leapfrog from HCFCs directly to tried and tested, environmentally safe natural refrigerants. Natural refrigerants not only have the potential to meet present needs, but can easily fulfil our future ones. Leapfrogging to natural refrigerants is of utmost importance especially since developing countries are already transitioning from HCFCs to HFCs, it is crucial that this scenario is avoided.

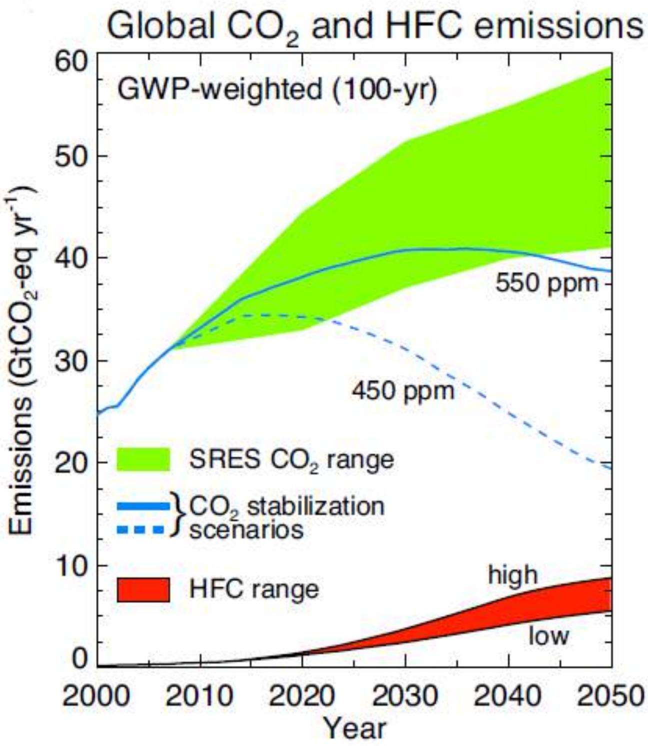
For this purpose, this research paper seeks to identify manufacturers of natural refrigerants in India and assess the existing state as well as potential for growth and future uptake of Natural Refrigerants in India across all the applicable Intergovernmental Panel on Climate Change (IPCC) Sectors: Refrigeration (Domestic, Commercial, Industrial, Transport) and Stationary Airconditioning (Residential, Commercial) & Mobile Airconditioning. Thereby, calling on industries, corporates, and the government to rapidly phase out HFCs by leapfrogging to natural refrigerants in an attempt to mitigate climate change and avoid its devastating impacts especially since the Indian proposal to phase out suggests a phase out starting from 2031, and a complete phase out only by 2050.

Figure 1 | Global ODS and HFC Emissions



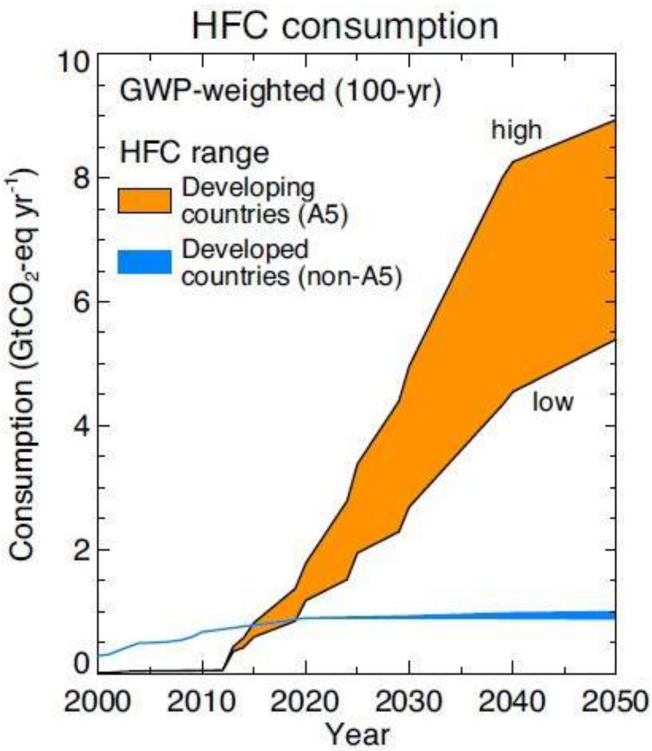
Source: Velders et al, 2009

Figure 2 | HFC vs CO2 Emissions



Source: Velders et al, 2009

Figure 3 | Growing HFC Market



Source: Velders et al, 2009

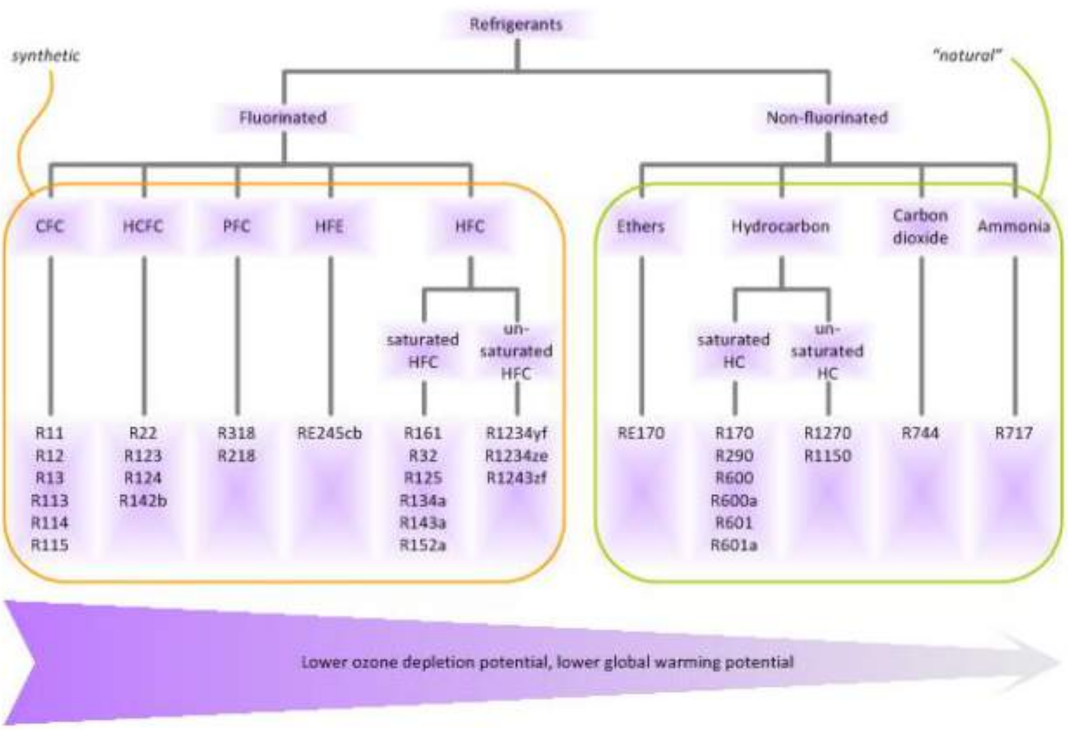
1.1 Conventional Refrigerants and Refrigeration Technologies in India

Refrigerants used in the Air conditioning and Refrigeration sectors can be classified under two key categories (*see Figure 4*):

1) **Conventional or Fluorinated/Synthetic refrigerants**: CFCs, HCFCs, PFCs, HFEs and HFCs are the most common categories of conventional refrigerants used in the refrigeration industry. However, use of these chemicals pose a great threat to the environment, hence need to be phased out from the global market.
2) **Natural refrigerants**: Hydrocarbons, Ammonia, Carbon dioxide, Water, Ethers, and even Air are new emerging refrigerants and they are making way in the commercial, industrial and residential sectors of the refrigeration and air conditioning industry. These are more energy efficient and cause significantly less or no damage to the environment.

As compared to natural refrigerants, synthetic refrigerants not only offer lower performance, they additionally pose higher Global Warming Potential (GWP, *as seen in Table 4*), hence, face an uncertain future (IITK, n.d.). These chemical compounds are non-toxic and non-flammable, so their use in cold storage and air conditioning systems is considered safe for the occupants and/or the operators. However, chlorinated and fluorinated refrigerants are Ozone Depleting Substances and also contribute to global warming and therefore, play a huge role in accentuating climate change. For these reasons, their use is being discouraged world over.

Figure 4 | Classification of Refrigerants



1.1.1 Conventional Refrigerants

- **CFC (ChloroFluoroCarbons):** CFCs have been extensively used in the last five to six decades as refrigerants in air conditioning and refrigeration systems. Since the Montreal Protocol was adopted in 1986, they have been banned for their high Ozone Depleting Potential (ODP). Examples of CFCs are R11, R12 and R115.
- **HCFC (HydroChloroFluoroCarbons):** The banning of CFCs gave way to popularization of HCFCs by slow conversion of CFC systems into HCFC system. The HCFCs comprise of much less quantities of Chlorine as compared to CFCs, hence lower ODP potential. However, the conversion process is costly and problems related to the availability of HCFCs are persistent, which were supposed to be temporary substitutes for CFCs. The use of HCFCs in new equipment was banned by EU in 2001. Common HCFCs include R22, R123 and R124.
- **HFC (HydroFluoroCarbons):** Since HFCs do not contain Chlorine, they are not detrimental for the ozone layer and are non-flammable, non-toxic and have comparable cycle efficiency. However, their global warming potential is extremely high (up to 2088 CO_2e/yr) as compared to other conventional refrigerants. Therefore, they are listed under the Kyoto Protocol to the United Nations Framework Convention on Climate Change (UNFCCC) from 2005 as substances whose emissions are to be limited or reduced (UNEP, 2009). Several countries have already introduced laws that restrict the use of HFCs. The EU seeks to phase down HFCs to 21% of current levels because of prevailing F-Gas Regulation (EIA, 2015).

1.1.2 Conventional Refrigerants Technologies

1) **Air Conditioning,** is the process of controlling temperature, humidity and ventilation of enclosed spaces across the following key applications:
    - **Industrial air conditioning** includes space cooling to solve the overheating issues of electronic equipment such as electronic manufacturing machinery, computer servers, testing instruments, temperature sensitive production, to increase thermal efficiency of power plants etc.
    - **Commercial air conditioning** includes all space cooling requirements in commercial centers such as offices, shopping malls, hospitals, airports etc.
    - **Residential air conditioning** includes indoor air conditioning for cooling households.
    - **Transport air conditioning** includes space cooling within passenger vehicles like cars and commercial vehicles like buses, trains and aircrafts.

2) **Refrigeration** can be termed the process of moving heat from one location to another under controlled conditions. Common applications of refrigeration include food preservation, processing and distribution, chemical & process industries as well as cold storage.
    - **Industrial refrigeration** includes large scale refrigeration used by food manufacturing industries such as dairy production, chemicals and pharmaceuticals storage, and cold warehouses.
    - **Commercial refrigeration** includes refrigeration for commercial establishments, for example, chillers and vending machines in supermarkets.
    - **Domestic refrigeration** includes household refrigerators.
    - **Transport refrigeration** includes the use of refrigeration in freight transport, such as refrigeration used for food containers.

1.1.3 Current sectorial uptake in India

Methodology

In order to estimate the current consumption of HCFCs and HFCs in India, IPCC Refrigeration, Stationary Airconditioning, and Mobile Airconditioning sub-sectors were identified and considered for this study. Sectors are categorised *in Table 1*. Raw market data in terms of stock and sales of units from 2006 till 2015 across all of these sectors were collected from several data banks, research papers and/or one-to-one communication with organizational representatives such as CLASP, GoI (Ozone cell, MoEF, & UNDP) report on HCFC Phase-out Management Plan (HPMP Stage-I), RAMA, ISHRAE, LBL, GIZ, Indiaenergy.gov.in, etc. Data received in units of stock and sales were converted to tons of charge, essential for calculating consumption of refrigerants. GHG emissions from these refrigerants were calculated using the leakage rate and available charge data. Data wherever applicable is either actual, reported and/or speculated, calculated (based on specific assumptions) data. Both data types were compared and analyzed using regression analysis to come up with the final estimation of consumption data.

Raw data from various sources was consolidated using regression analysis to end up with organized figures for the period from 2001 to 2015. Similar regression analysis was carried out for multiple data types to obtain projections from 2016 to 2030. For sales figures from 2016 to 2030, CAGR values & reported sales data up to 2015 were used. For those years where the CAGR wasn't available, it was assumed to be 10% (which is the average growth expected for the HVAC industry from 2016 to 2020 according to HPMP Stage II). In cases where the sales values were not available at all, effective sales were estimated based on change in stock and thereafter industry specified CAGR values were used to calculate numbers for either side of 2010. Stock analysis was carried out as per: 1) Reported sales & equipment life-span, 2) CAGR sales & equipment life-span, 3) Regression equation from reported stock. Figures from three cases were analyzed to obtain an equation for a best-fit line and final stock projections for 2016 to 2030 were done using the obtained equation.

Table 1 | IPCC Sectors and corresponding equipment

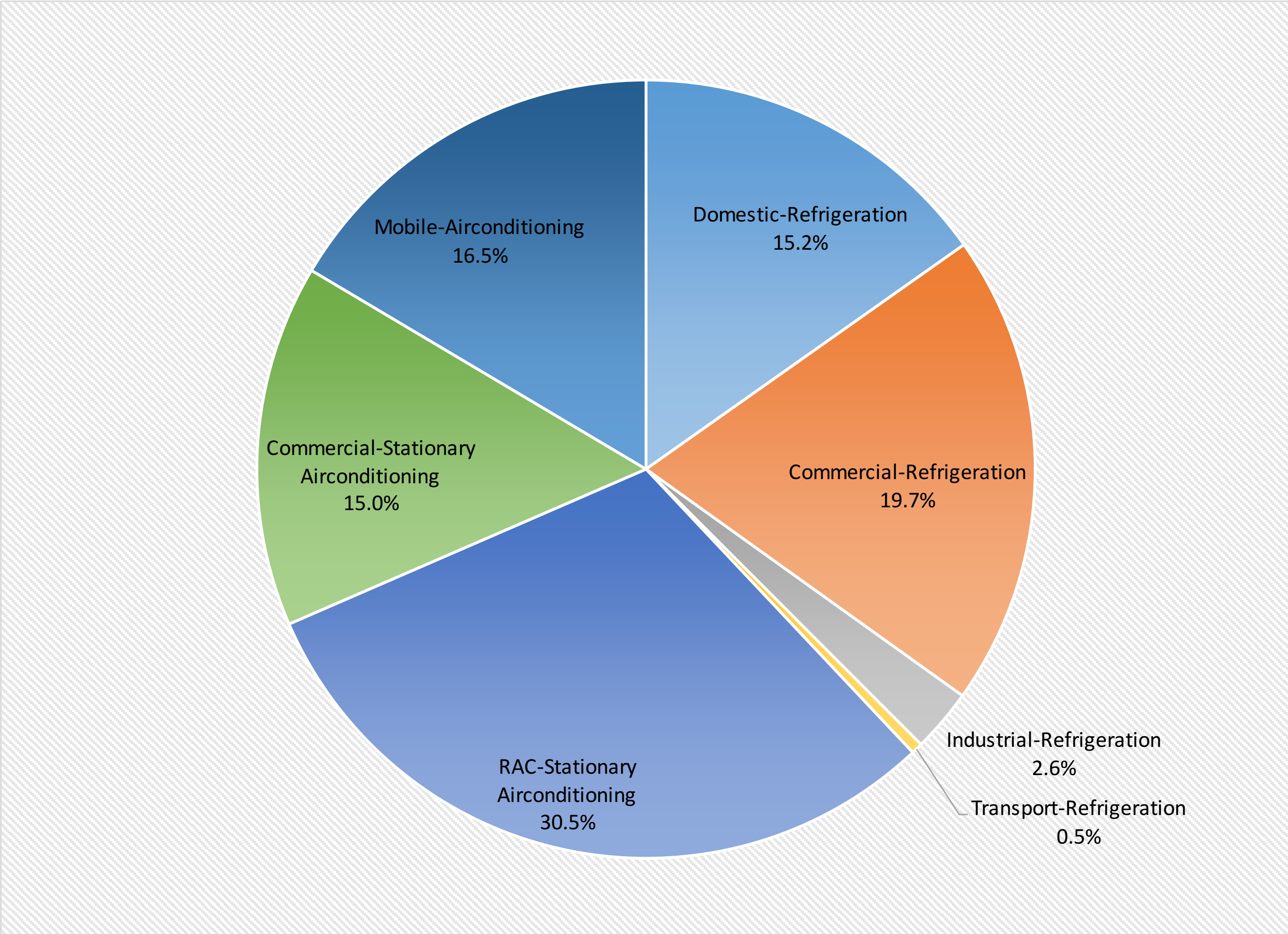
IPCC Sector	IPCC Sub-Sector	Equipment Sub-Type
Refrigeration	Domestic	Direct Cool & Frost Free Refrigerators
Refrigeration	Commercial	Remote Condenser Reach-in Cooler
Refrigeration	Commercial	Integrated Reach-in Cooler
Refrigeration	Commercial	Water Coolers
Refrigeration	Commercial	Process Chillers
Refrigeration	Commercial	Milk Chillers
Refrigeration	Industrial	Cold Storage
Refrigeration	Industrial	Ice-Cream Machines
Refrigeration	Transport	Reefer Vehicles
Stationary Airconditioning	RAC	Window/Splits/Cassettes/Inverter/Floor Mounted
Stationary Airconditioning	Commercial	Ductable Splits / Packaged AC
Stationary Airconditioning	Commercial	VRV/VRFs
Stationary Airconditioning	Commercial	Chillers
Mobile Airconditioning		

Source: IPCC

Results

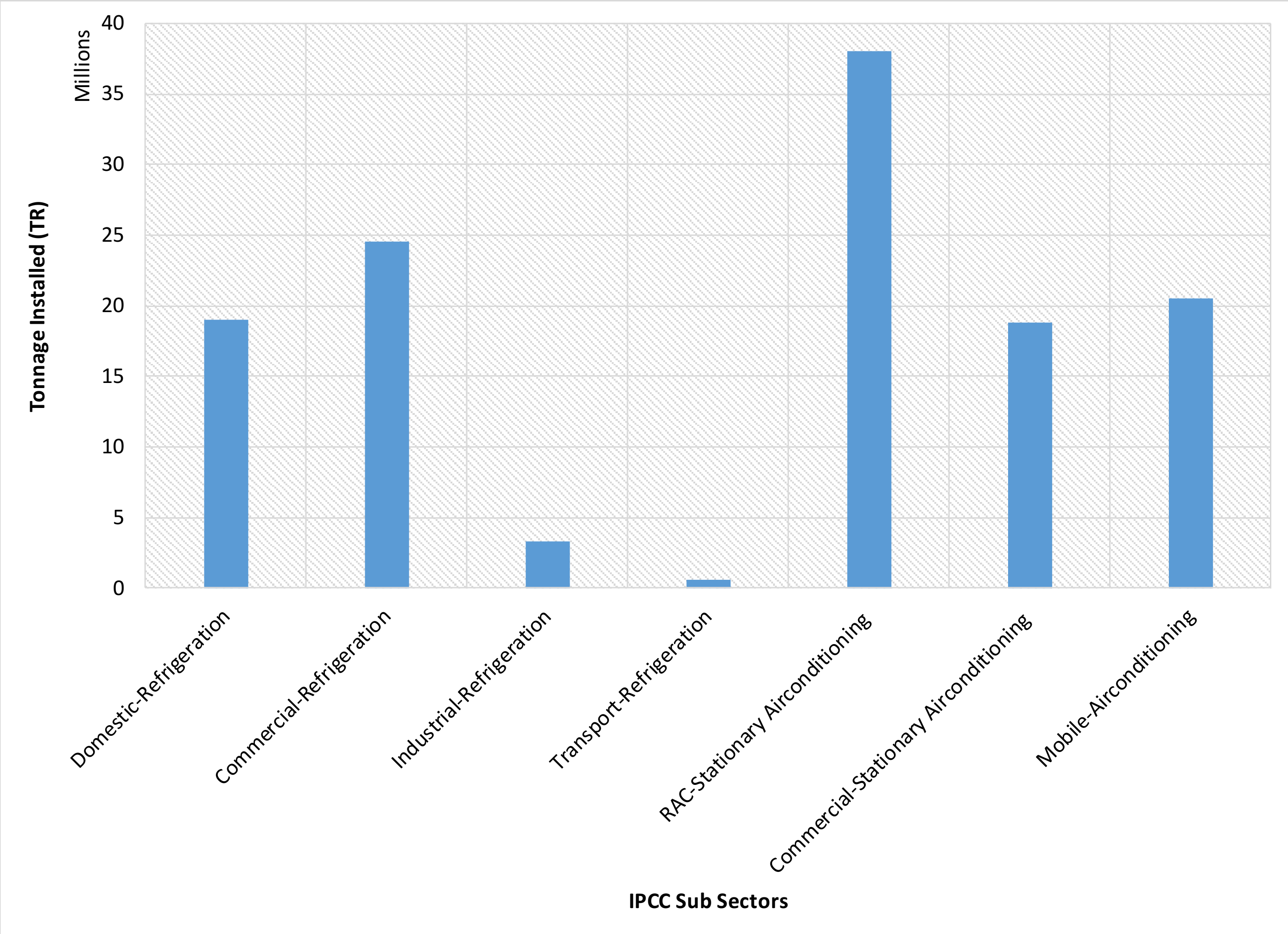
In 2015, out of all the studied sectors, the Airconditioning sector formed the major chunk with a 62% market share towards refrigerant consumption, comprising of HCFCs, HFCs as well as NR, *as seen in Figure 5.* While commercial refrigeration is estimated at 51.8% of the total refrigeration based consumption, maximum consumption in terms of tonnage was observed by the room Airconditioning sector at 38 million TR, followed by commercial refrigeration at 24.5 million TR *as seen in Figure 6*. Industrial and transport refrigeration sectors observed the lowest estimated consumption in 2015.

Figure 5 | IPCC Sector Wise Tonnage Installed (%) in India, 2015



Source: cBalance Solutions Hub analysis

Figure 6 | Total Tonnage installed (2015)

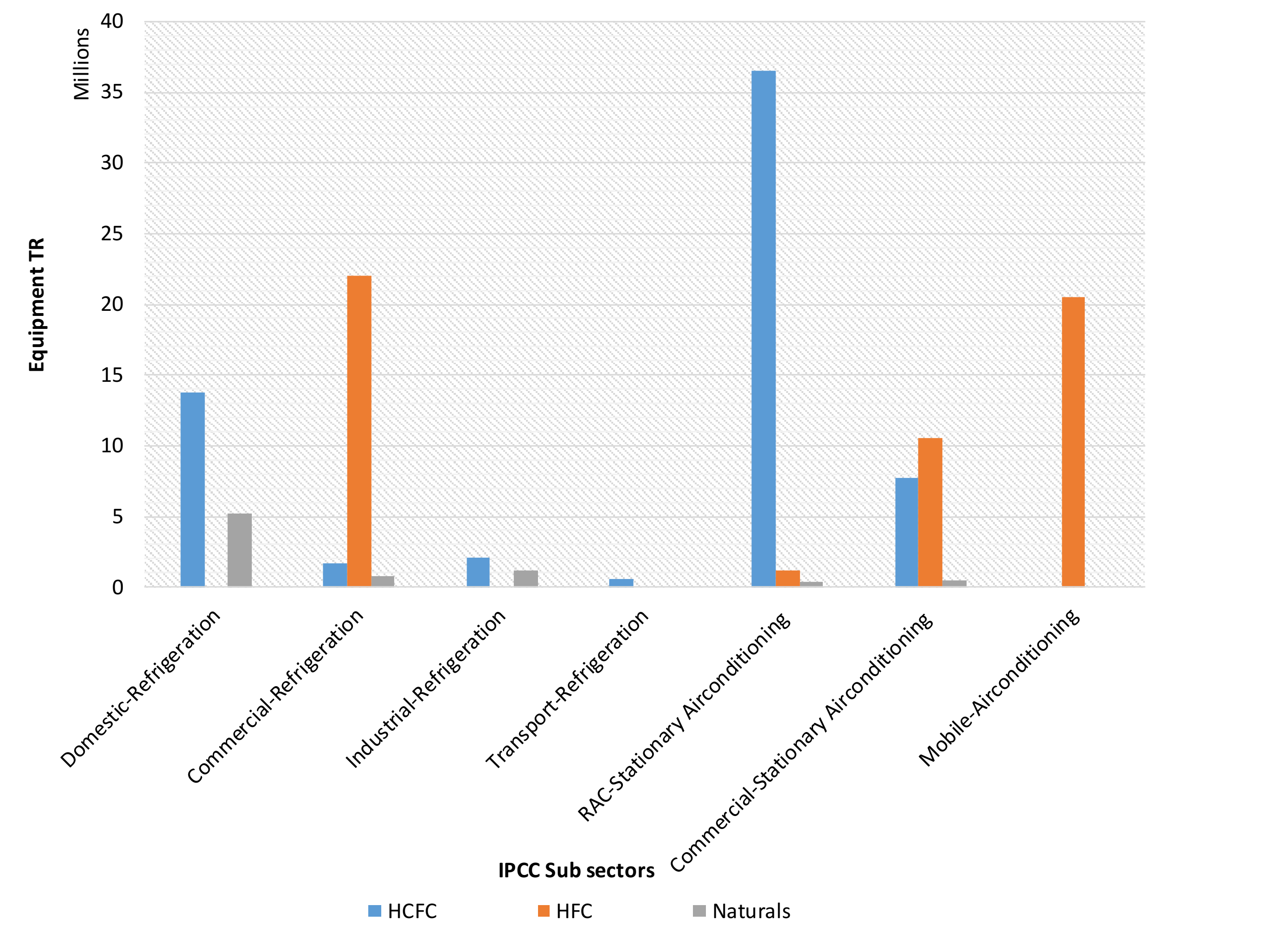


Source: cBalance Solutions Hub analysis

According to data and subsequent projections, HFC consumption in terms of equipment TR was fast closing in on the corresponding HCFC consumption in 2015. By 2015, 62 million TR of cooling was by HCFCs, 54 million TR by HFCs and 7 million TR by Natural refrigerants. Natural refrigerants contributed to 6.4% (7.99 million TR) of the total equipment TR sold, see *Figure 11*. The commercial refrigeration sector witnessed highest HFC consumption at 22 million TR, followed by mobile Airconditioning at 20 million TR. Maximum consumption of Natural refrigerants came from the domestic refrigeration sector at 5 million TR, followed by industrial refrigeration at 1 million TR (*see* Figure 7).

As observed, it is not surprising that maximum emissions came from the same sectors that showcased maximum refrigerant consumption. HCFC emissions from the room Airconditioning sector were highest at 15 MT CO2e in 2015, followed by emissions from HFCs under the commercial refrigeration sector at 8.9 MT CO2e in 2015. Emissions from the mobile Airconditioning sector were estimated at 7.97 MT CO2e (see Figure 8). Furthermore, the overall emissions from HFCs were almost equivalent to emissions from HCFCs in the year 2015. Evidently, these sectors need to be given priority if a transition to NR is planned and successful.

Figure 7 | IPCC Sector wise Refrigerant Equipment TR (2015)



Source: cBalance Solutions Hub analysis

Refrigerant uptake under the refrigeration sub-sectors in 2015

Consumption of refrigerants across the domestic refrigeration sector in 2015 was dominated by HCFCs, primarily R22 and R141b. R22's share is estimated at 27%, while that of R141b was 35.8% with a combined share of 63%. There is a huge potential of growth of R290 based systems in this sector. Furthermore, within the commercial refrigeration sector, it was observed that the dominant refrigerants in current use were R22, R141b and R134a. They seize a significant share of 96.8% along with R124 and R404a, with natural refrigerants (including R717 & R744) constituting the remaining 3.2%.

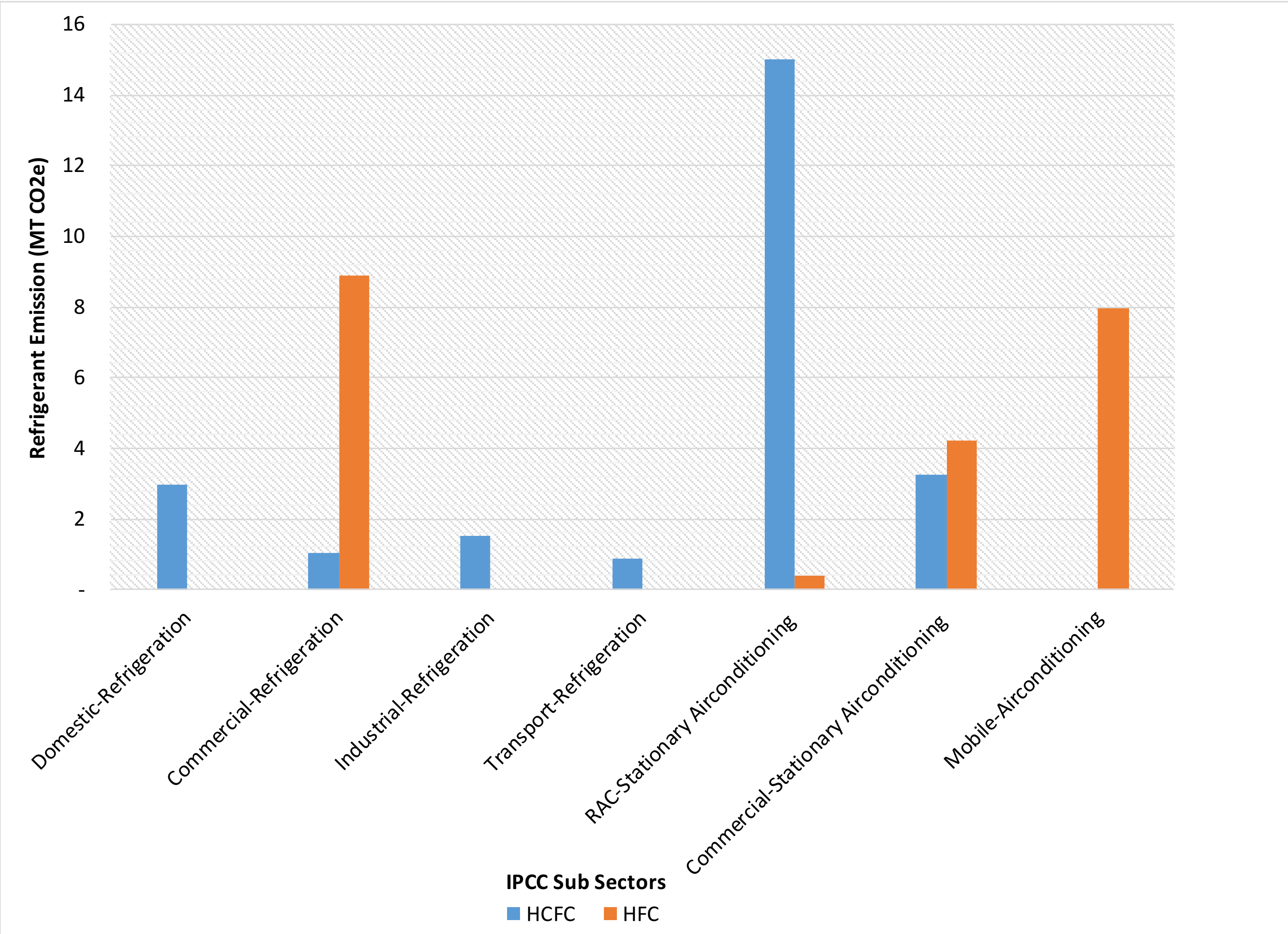
Unlike in the commercial refrigeration sector, refrigerant use in the industrial refrigeration sector is varied. Based on equipment TR, the share of HCFCs (R22, R141b, R142b & R124) in this sector is 63.8% and the remaining 36.2% is covered by Natural refrigerants (R717 & R290). Industrial sector is the only sector with a majority of natural refrigerant uptake (in terms of stock) of 71%, primarily comprising of R717 units, which is 69.7% and 0.06% from R290 units. HCFCs dominate consumption in the transport refrigeration sector with R22 and R141b contributing 86.8% to the uptake of equipment TR in this sector, followed by R142b (6.6%) and R124 (6.6%).

Refrigerant uptake under the Airconditioning sub-sectors in 2015

The residential Airconditioning sector saw maximum refrigerant consumption from R22 at 94%, 2.6% came from R410A, 1.8% from R123, 0.9% from R290 and only 0.5% from R32. HCFCs constitute 95.9%, while 3.2% is HFCs and 0.9% natural refrigerants. In sectors such as residential Airconditioning, where the transition has not yet begun, or is in the nascent stage, leapfrogging to natural refrigerants such as R290 would be reasonably easier and feasible especially considering that the technology is already known to work and further, is economically viable to the end user when the entire life cycle is considered.

With respect to the commercial Airconditioning sector, HFC 134a forms the chunk of all the refrigerants consumed in 2015. It constitutes 53% of the total consumption, followed by HCFC 22 with a 41% uptake. Further, in the case of mobile Airconditioning, the only refrigerant used, R134a's uptake in 2015 was 20 million TR.

Figure 8 | Refrigerant Emissions- Conservative Scenario (2015)

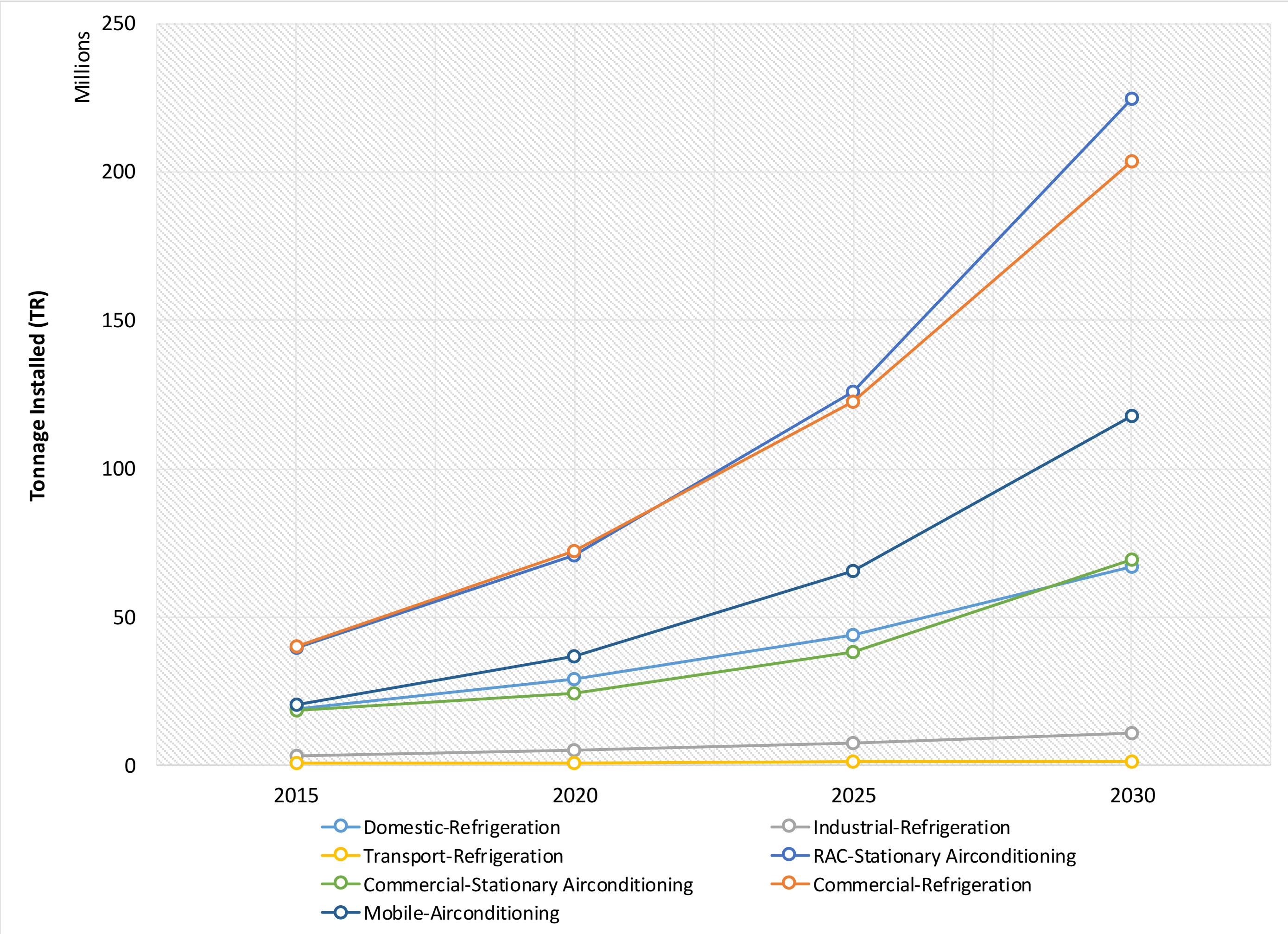


Source: cBalance Solutions Hub analysis

1.1.4 Sectorial growth projections

Based on the methodology highlighted in section 1.1.3, calculations to project growth of refrigerants suggest a 4-time growth for commercial refrigeration and an increasing trajectory for all sectors, however, by varying growth rates. Room Airconditioning sector witnesses the maximum growth towards installed tonnage with a 5.6-fold increase in 2030 from 2015 levels, it increases from 38 million TR in 2015 to 216 million TR in 2030. Such a significant growth would essentially result in proportional increase in emissions from HFCs and HCFCs, suggesting the importance of leapfrogging to NRs. Figure 9 shows the sector wise tonnage projection from 2015 till 2030.

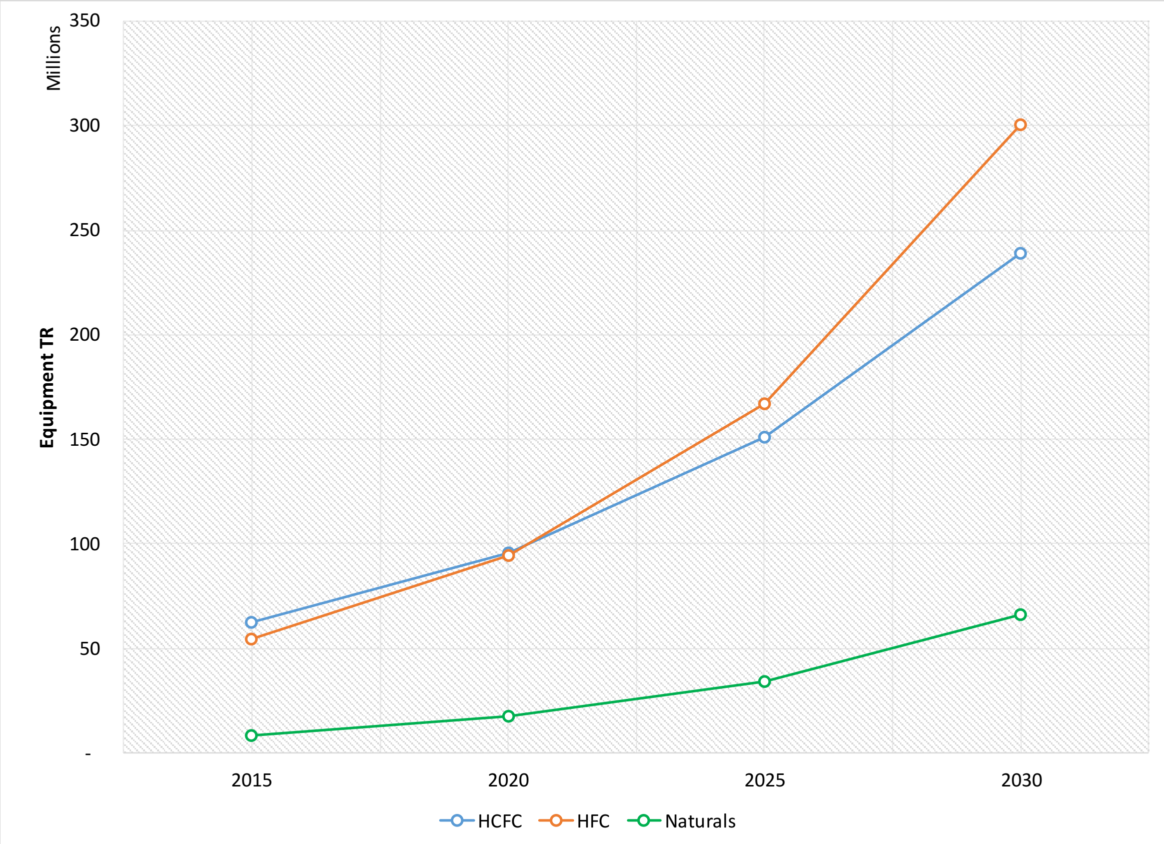
Figure 9 | IPCC Sector-wise Tonnage projection (2015-2030)



Source: cBalance Solutions Hub analysis

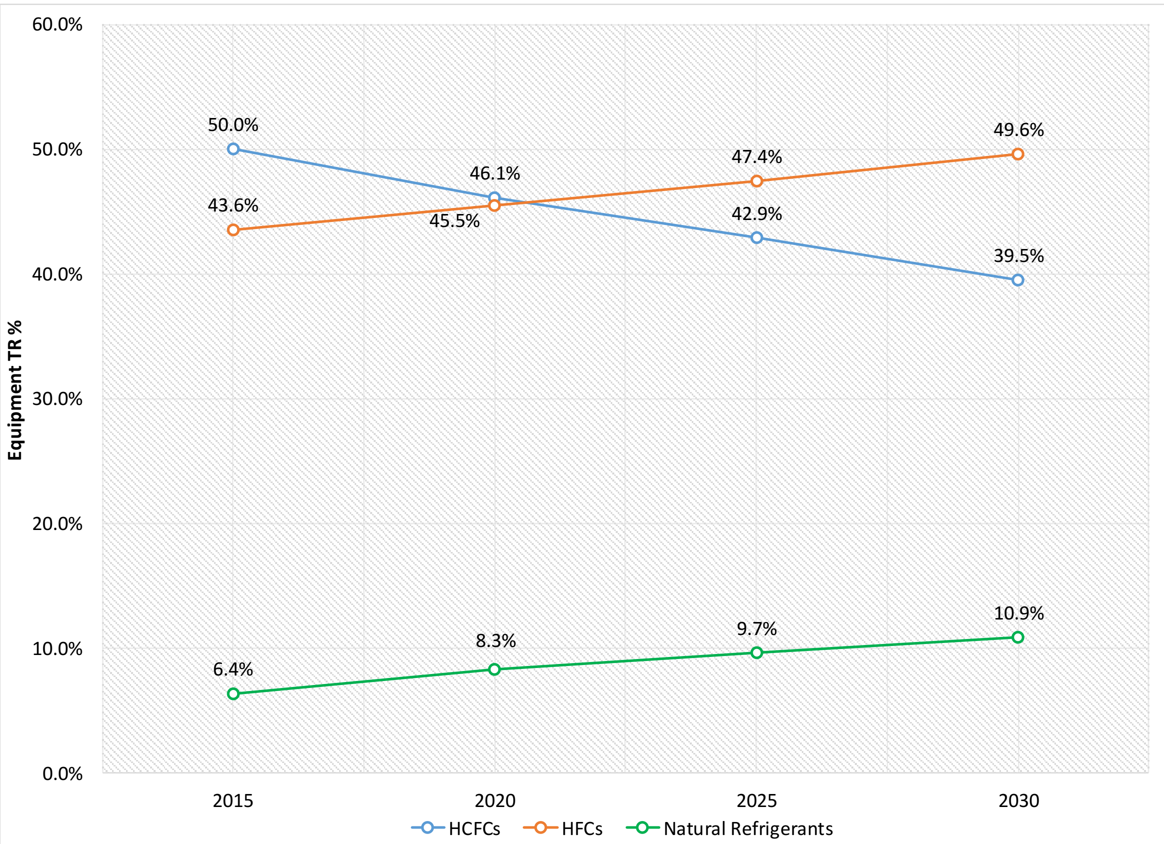
HFCs and HCFCs continue to growing steadily till 2030, however, NRs show a very gradual escalation, especially under the current policy regime. HFCs grow 5.4 times in 2030 as compared to 2015 levels, doubling approximately every 10 years. HCFCs witness a 3.8-fold growth in 2030 over 2015 levels. Emissions as seen in *Figure 12* are projected to grow proportional to growth in consumption of the refrigerants, except for the case of NRs, as most natural refrigerants have zero GWP and ODP. Figure 10 & Figure 11 show the equipment TR projections from 2015 to 2030, classified on the basis of refrigerant types.

Figure 10 | Refrigerant wise Equipment TR projection (2015-2030)



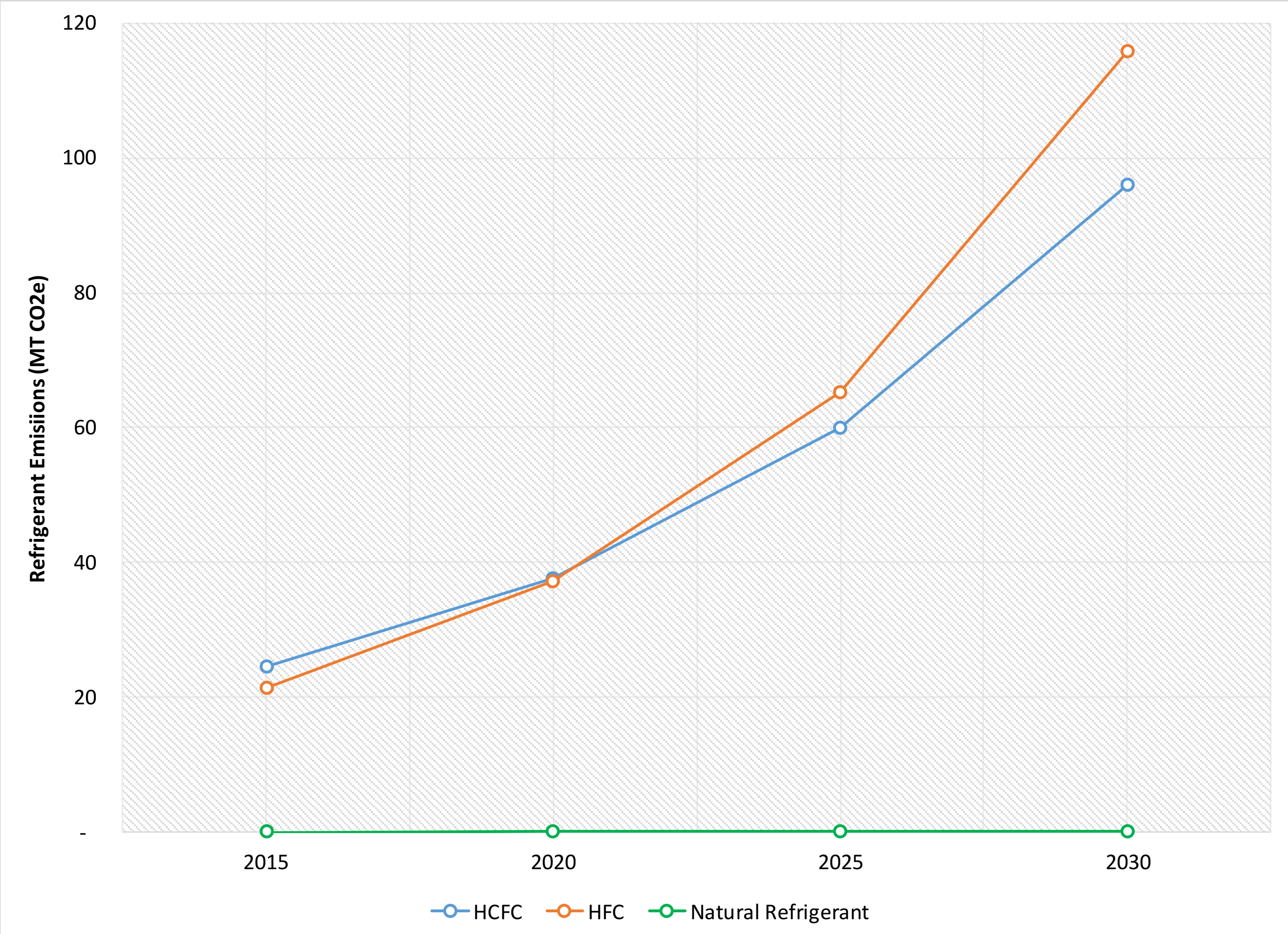
Source: cBalance Solutions Hub analysis

Figure 11 | Refrigerant wise equipment TR % (2015-2030)



Source: cBalance Solutions Hub analysis

Figure 12 | Refrigerant Emissions Projection (2015-2030)

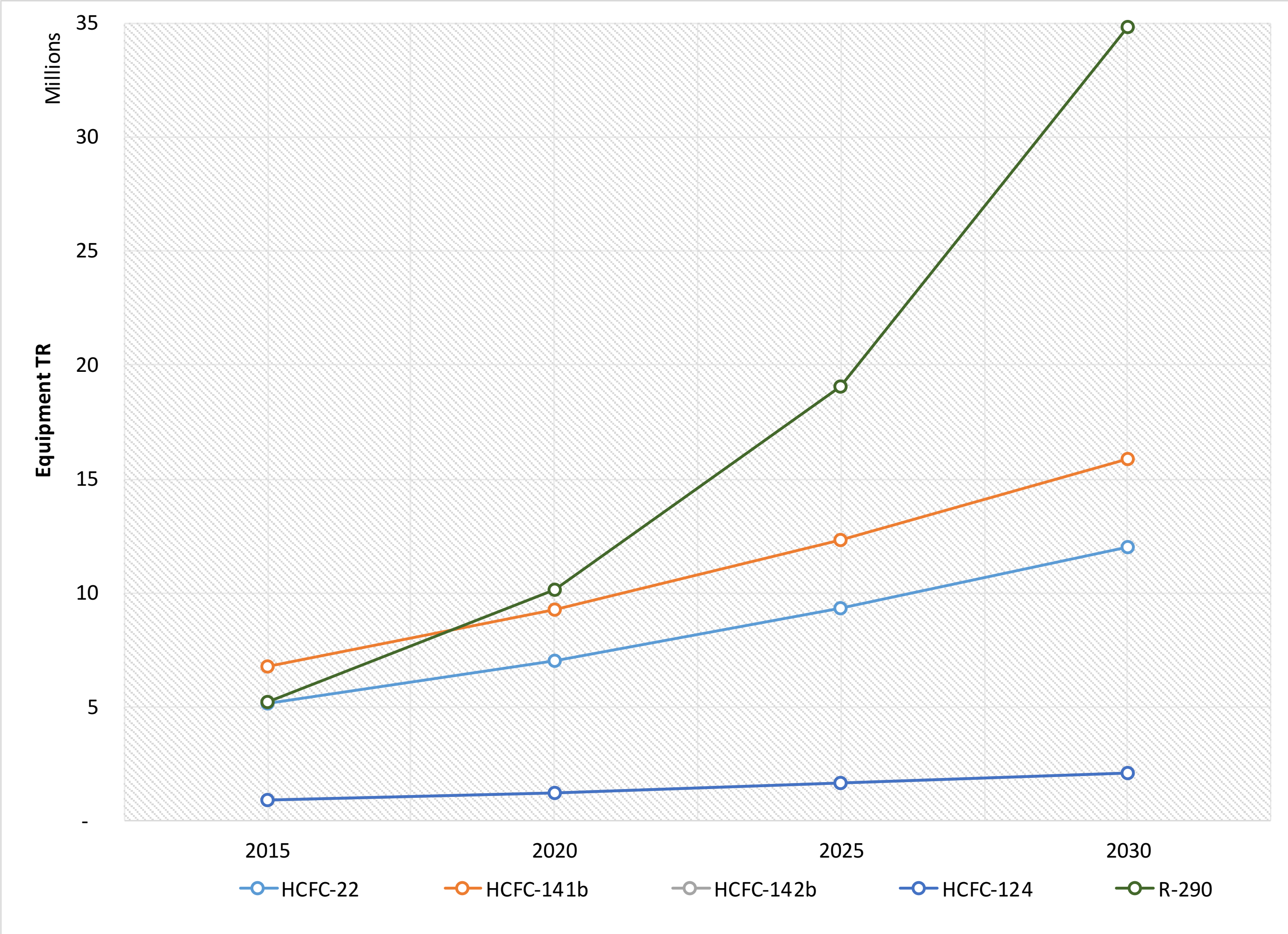


Source: cBalance Solutions Hub analysis

Refrigerant uptake under the refrigeration sub-sectors from 2015 to 2030

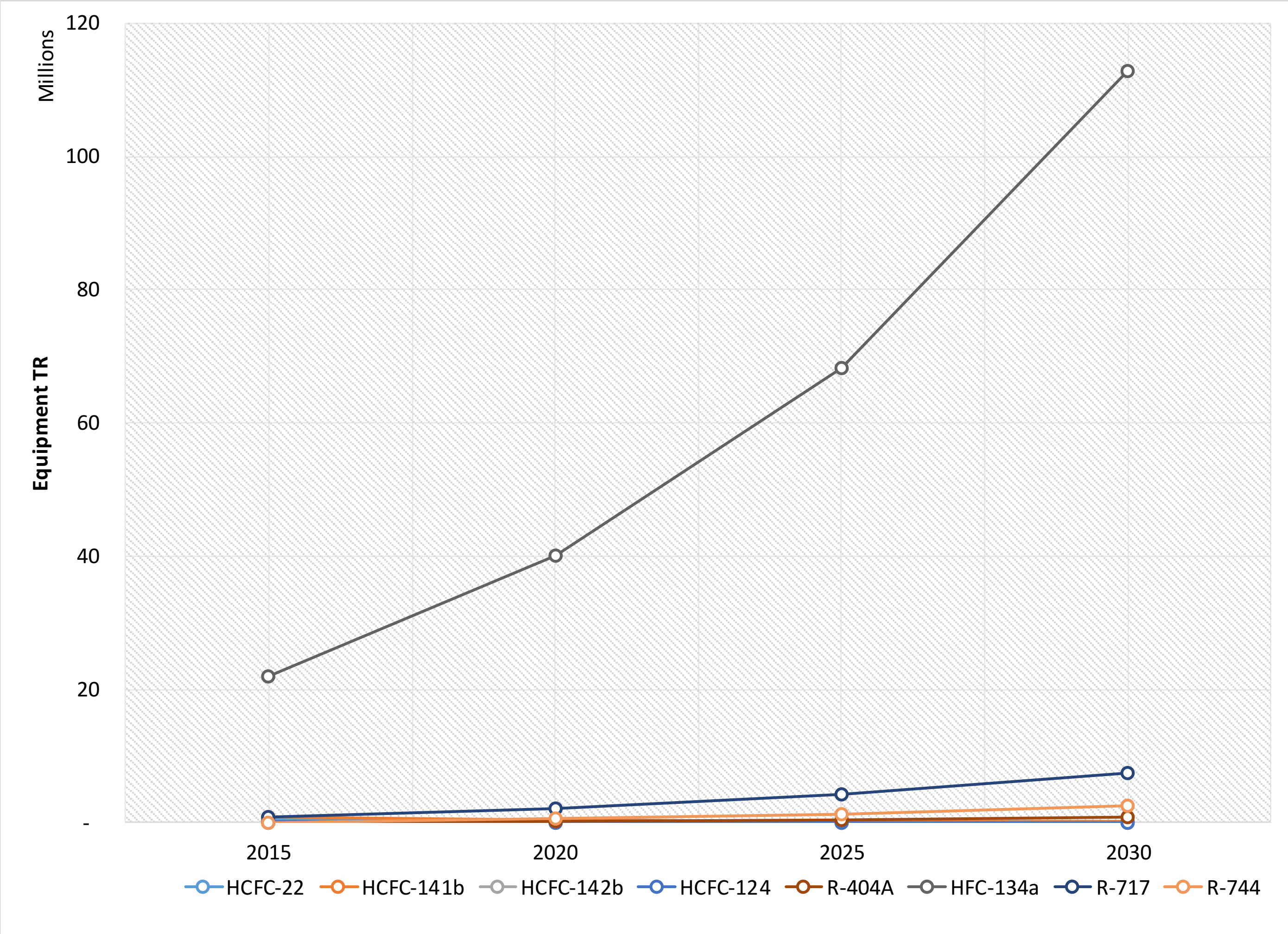
All refrigerants under the *domestic refrigeration sector* project a significant growth under business-as-usual other than HCFC 124 as seen in *Figure 13*, which witnesses a nominal growth. Natural refrigerant R290 is estimated to grow 6.6 times by 2030 with a share of 52% as compared to 2015 levels with a share of 27.6%. R290 will be the most commonly used refrigerant for domestic refrigeration followed by R141b (23.7%) and R22 (17.9%) in 2030. Sector based consumption of HCFCs are estimated to drop from 72.4% in 2015 to 47.9% in 2030, while that of NRs is estimated to grow from 27.6% in 2015 to 52.1% in 2030. Uptake of HFCs under BAU is zero or negligible in this sector. Under the *commercial refrigeration* sector dominated by R134a, the share of HFCs is expected to grow from 89.8% in 2015 to 91.9% in 2030. HFC 134a based equipment shows 5 fold-growth from 22 million TR in 2015 to 113 million TR in 2030. HCFCs (R22, R141b, 142b, and R124) decline from 7% in 2015 to 0.17% in 2030. The NR trajectory witnesses a rise from 3.2% in 2015 to 8% in 2030. Figure 14 shows the equipment TR projection for the commercial refrigeration sector from 2015-2030.

Figure 13 | Domestic Refrigeration Equipment TR Projections (2015-2030)



Source: cBalance Solutions Hub analysis

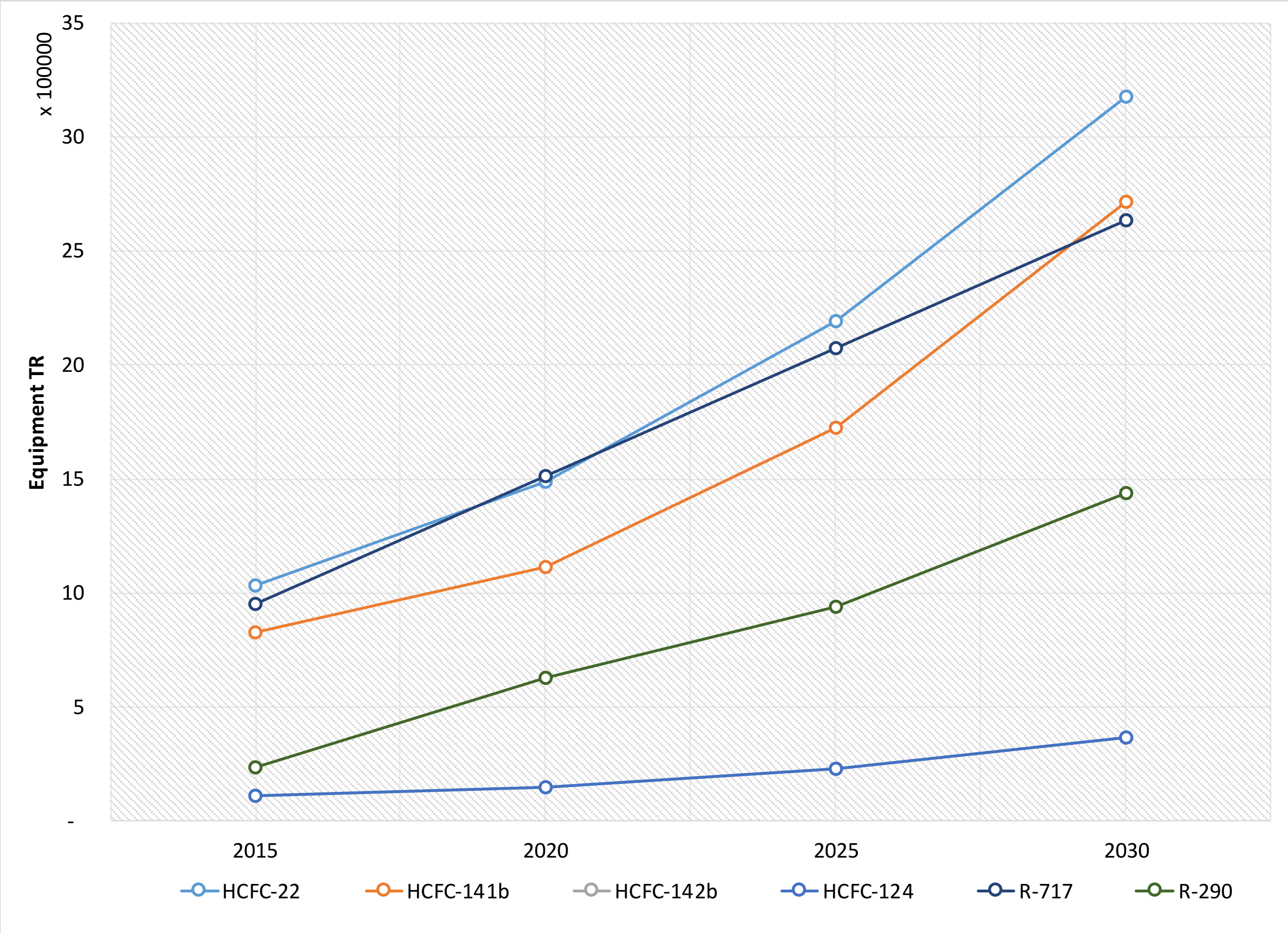
Figure 14 | Commercial Refrigeration Equipment TR Projections (2015-2030)



Source: cBalance Solutions Hub analysis

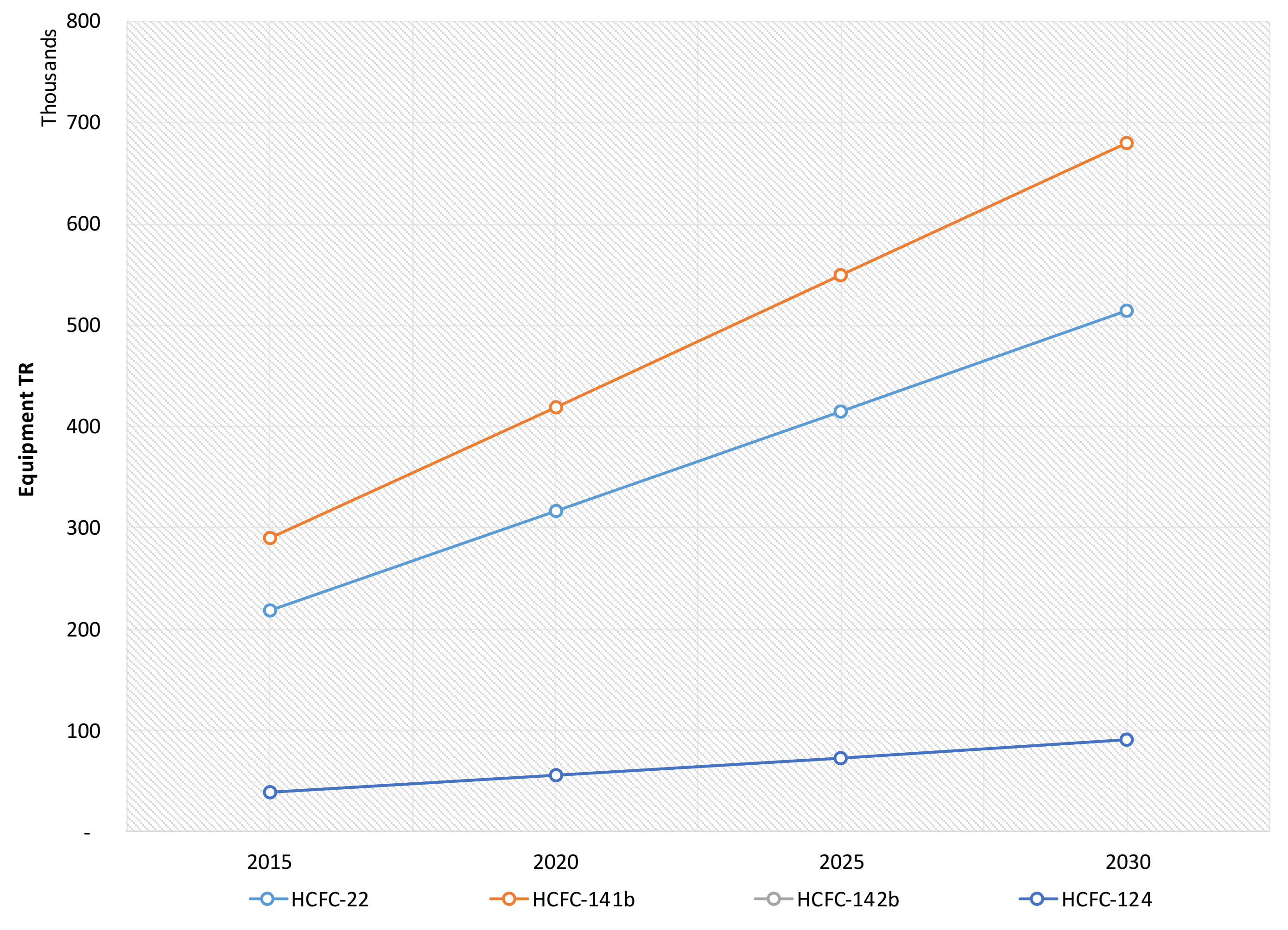
While the *industrial refrigeration* sector does not consume any HFCs in 2015, a status quo is expected to be maintained till 2030 for the same. However, both HCFCs and NRs continue to witness a growing trajectory as seen in *Figure 15*. R22 and R141b witness the maximum growth as compared to other refrigerants in this sector. While, the percentage share of HCFCs namely: R22, R141b, R142b, and R124 are expected to dip from 63.8% in 2015 to 61.9% in 2030, share of NRs (R717 and R290) would proportionally rise from 36.2% in 2015 to 38.1% in 2030. *Transport refrigeration* sector is estimated to be dominated by only HCFCs till 2030 *as seen in Figure 16*. HCFC share in this sector remains at 100% throughout. Refrigerant consumption in this sector comprises of R22, R141b, R142b and R124. Maximum consumption of R141b at 49.5% is estimated, followed by R22 at 37.4%, while R142b and R124 at 6.6% each.

Figure 15 | Industrial Refrigeration Equipment TR Projections (2015-2030)



Source: cBalance Solutions Hub analysis

Figure 16 | Transport Refrigeration Equipment TR Projections (2015-2030)

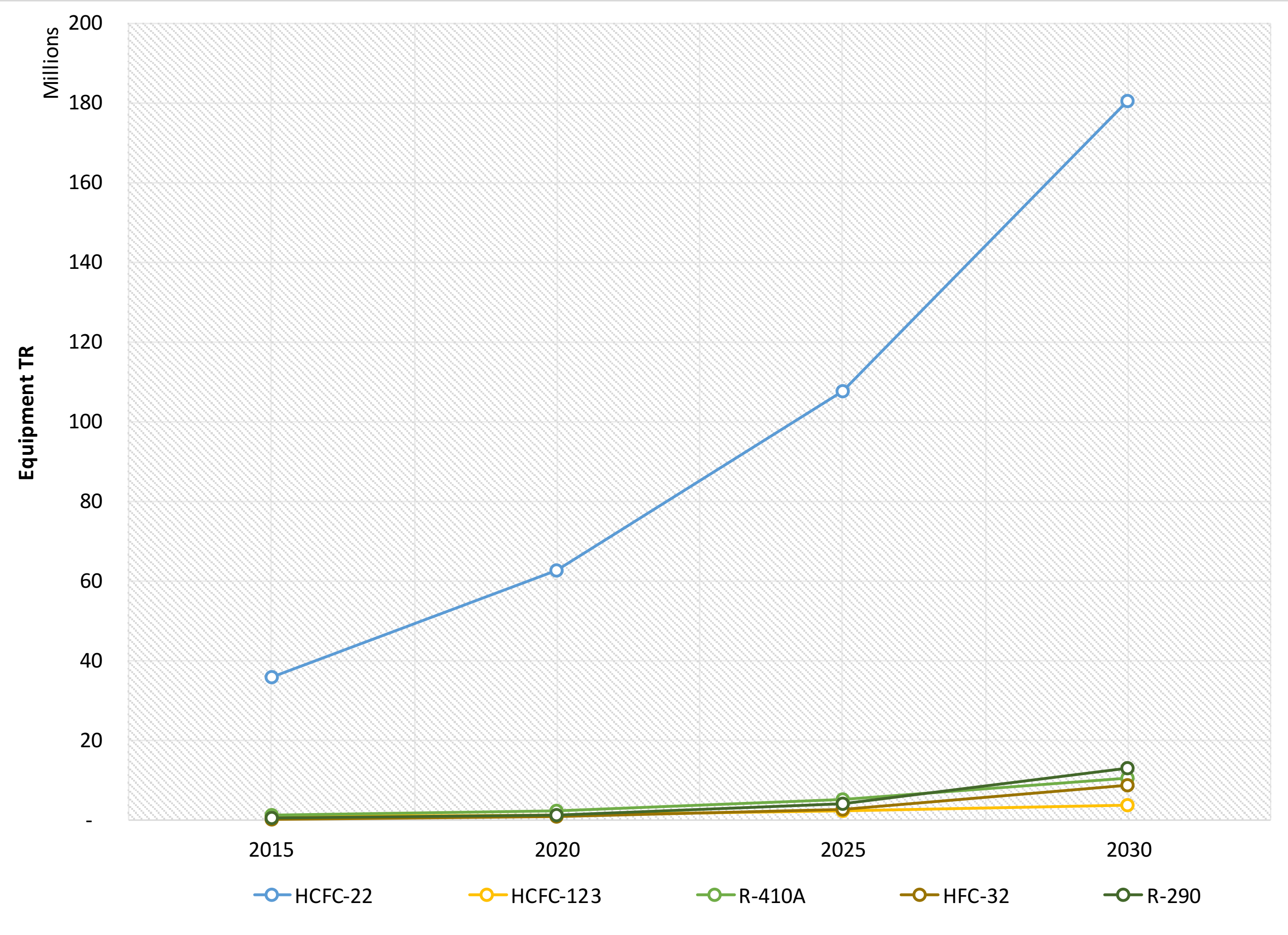


Source: cBalance Solutions Hub analysis

Refrigerant uptake under the Airconditioning sub-sectors from 2015 to 2030

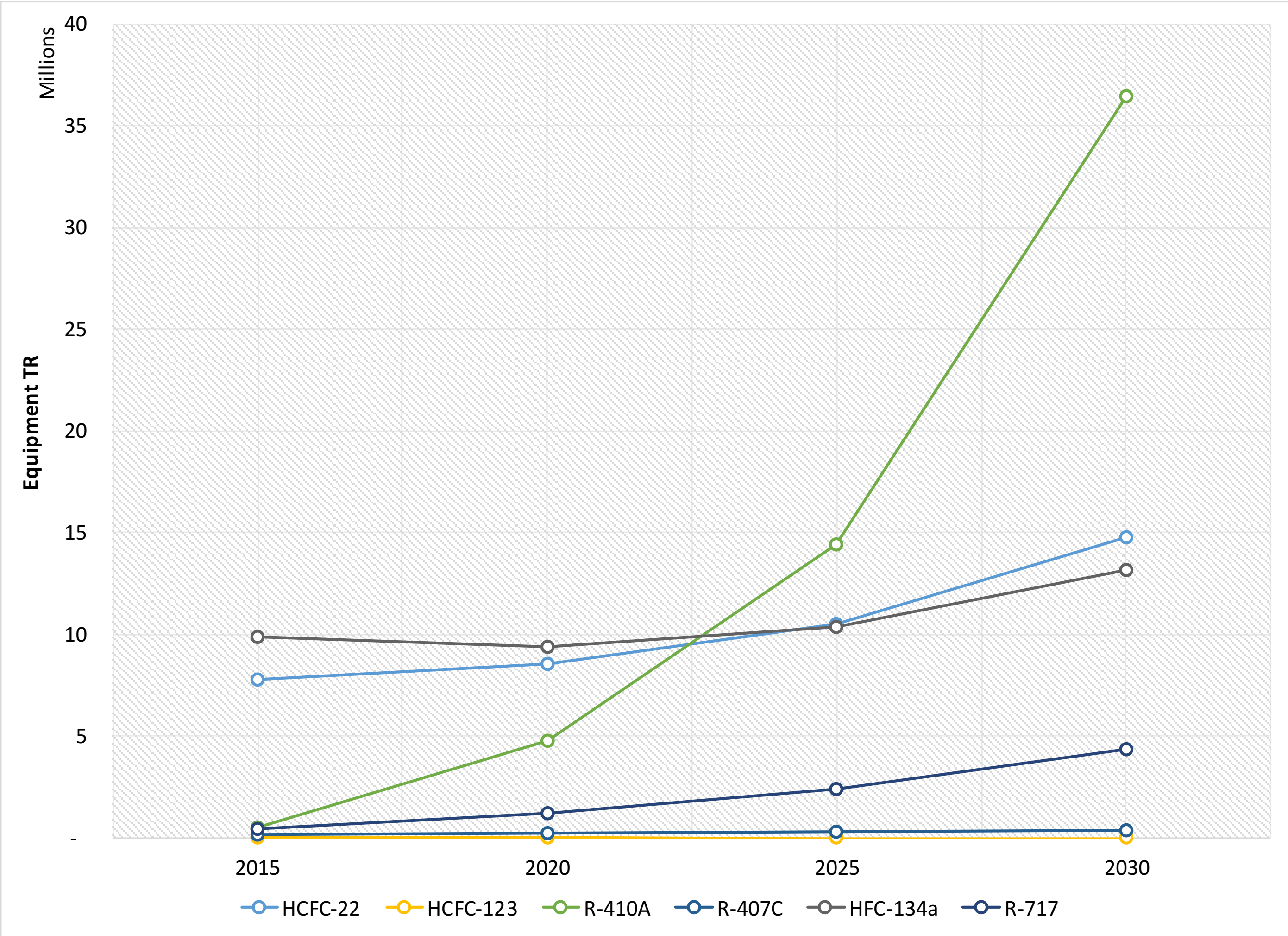
Under the *residential Airconditioning* sector, while R22 continues to grow significantly, its percentage share sees a declines due to a proportional increase in uptake of R410a, R123, R32 and R290. R22's share in the sector declines from 94% in 2015 to 83.6% in 2030, while R410a increases from 2.69% in 2015 to 4.77% in 2030. However, even though the share of HCFCs declines, a 5-fold increase is estimate from 36.4 million TR in 2015 to 184 million TR in 2030 *(See Figure 17)*. The share of NRs in this sector is estimated to increase from 0.91% in 2015 to 5.97% in 2030. With respect to the *commercial Airconditioning* sector, an increase in uptake of HFCs is estimated towards a proportional decrease in the rate of uptake of HCFCs. While HCFCs decline from 41.4% in 2015 to 21.4% in 2030, HFCs grow from 56.2% in 2015 to 72.3% in 2030. This is primarily attributed to the exponential growth estimated for R410a. It grows from 0.5 million TR in 2015 to 36.5 million TR in 2030 *as seen in Figure 18*. The uptake of NRs sees a very slow growth from 2.4% in 2015 to 6.3% in 2030. *Mobile Airconditioning* sector refrigerant uptake is estimated to be restricted to R134a till 2030 with the Indian automobile industry still undecided about its choice of an alternative refrigerant. It grows from 20.5 million TR in 2015 to 117.7 million TR in 2030, a 5.7-fold increase *(See Figure 19)*

Figure 17 | Residential AC Equipment TR Projections (2015-2030)



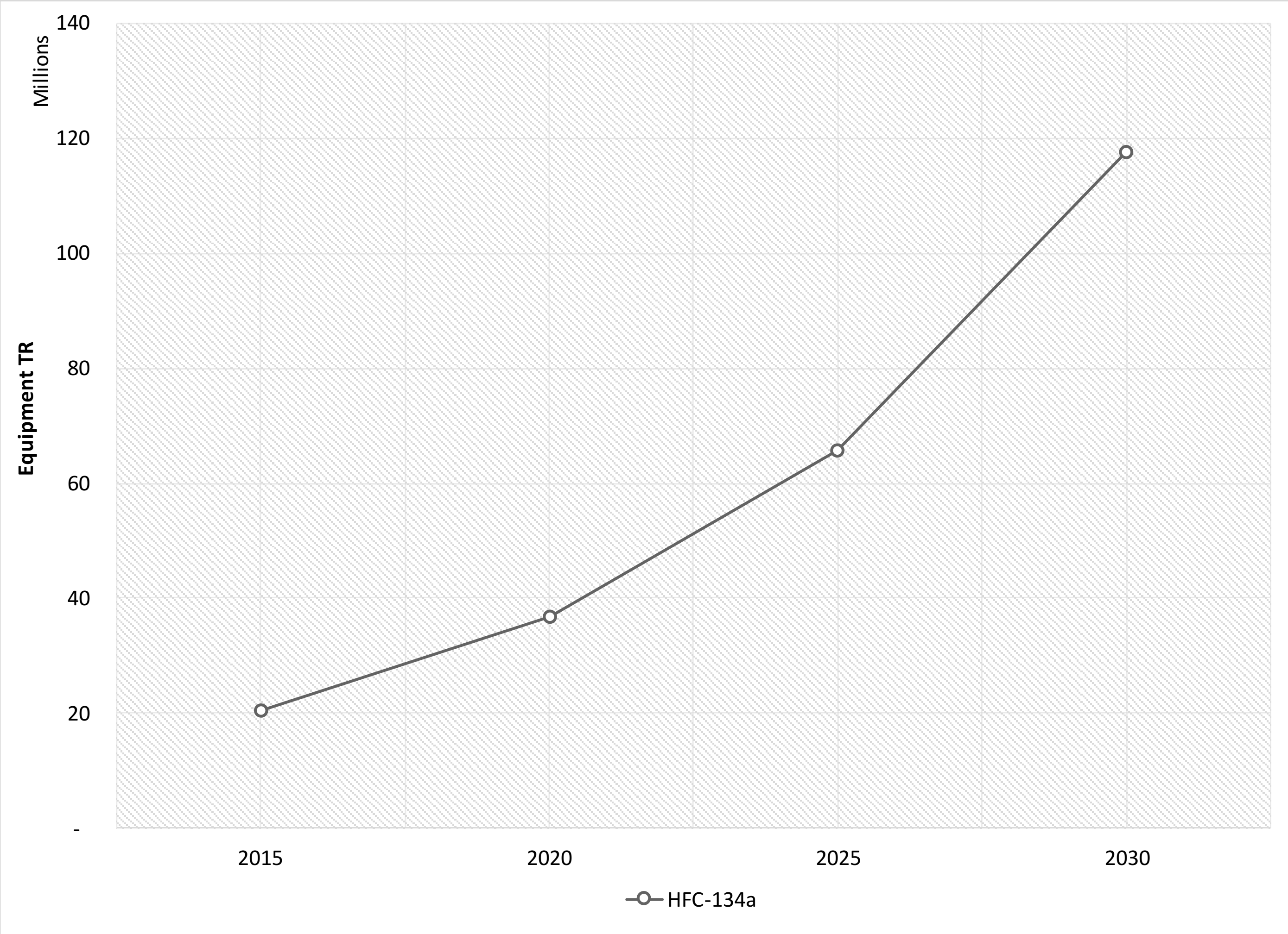
Source: cBalance Solutions Hub analysis

Figure 18 | Commercial AC Equipment TR Projections (2015-2030)



Source: cBalance Solutions Hub analysis

Figure 19 | Mobile AC Equipment TR Projections (2015-2030)



Source: cBalance Solutions Hub analysis

1.2 Types of refrigerants available and compatible technologies

1.2.1 Natural Refrigerants

Refrigerants used for the air conditioning and refrigeration applications are classified on the basis of their chemical composition. After it was discovered that conventional refrigerants i.e. the CFCs, HCFCs and HFCs pose a threat to the environment, there has been a constant movement towards replacing them with eco-friendlier and safer options. Hydrocarbons (propane, iso-butane etc.), ammonia, water and carbon dioxide are the more commonly used natural refrigerants in the air conditioning and refrigeration industry. These refrigerants when released into the atmosphere pose very low GWP and more so, their ODP is close to zero. Moreover, the systems that make use of these refrigerants are more energy efficient hence; the direct/indirect GHG emissions are also much lower.

- **HC (HydroCarbons):** HCs are an inexpensive alternative to HFCs, especially when compared with the environmental impact costs associated with conventional refrigerants. HCs do not pose any harm to the ozone layer and have a very low global warming potential, but their biggest shortcoming is that they are highly flammable. HCs are promoted with full enthusiasm by environmentalists and have made incredible progress. HC refrigerants are combustible which brings about safety issues in the production and residential units working with HC refrigerants. This issue calls for additional investments in manufacturing industries for increased safeguard concerns and layout changes for preventing any mishaps (James. R et al, 1997). Propane (R290) and iso-butane are common examples of hydrocarbon refrigerants. These are used in applications such as air conditioning in domestic and industrial sectors, domestic, commercial and industrial refrigeration, commercial and industrial refrigeration, chill cabinets and vending machines, heat pumps, low- and ultra-low temperature applications.
- **NH3 (Ammonia):** Ammonia (R717) has been employed in refrigeration systems since 1840 and is a potential alternative for HFC refrigerants. Ammonia has all the qualities for being considered an efficient refrigerant, mechanically and environmentally. However, Ammonia is not as popular, since it poses serious hazard when leaked and even miniscule concentrations of Ammonia can be a danger. Thus it is employed only in industrial and commercial sectors where stringent safety regulations are followed and skilled manpower is available for managing the refrigeration system (Swep.net, 2016). Ammonia as a refrigerant finds application in large air conditioning systems (chillers) and commercial & industrial refrigeration (storage, food, brewing, heat extraction, ice rinks etc.).
- **CO_2 (Carbon Dioxide):** CO_2 (R744), as a refrigerant was used in the industrial sector in the early 20^{th} century as it possesses several qualities, for example, it is non-flammable and is available in large quantities at low cost (Achrnews.com, 2004). However, significant innovations are required in carbon dioxide refrigeration cycle as carbon dioxide has lower efficiency and needs to be operated at high pressures. Air conditioning in the automotive industry is a potential sector where carbon dioxide can be employed on a large scale. At present carbon dioxide is used in vending machines, warehousing, static/mobile air conditioning systems, commercial refrigeration, chill cabinets and process chilling, applications involving “low and ultra-low-temperature”.
- **Water**: From an environmental standpoint, Water (R718) is the ideal substance and a very frequently used fluid for the applications of fluid transfer for air - conditioning and refrigeration. The thermodynamic properties of water (very low vapor pressure and freezing point at 0 °C) limit its use as refrigerant for applications above 0 °C, for example, large chillers having good energy efficiency. As water is easily available and has favorable thermodynamic and chemical attributes, it is one of the very first refrigerants used in the refrigeration industry. In spite of its advantages, there are

various challenges that surface due to the high specific volume at low temperatures, very high pressure ratios have to be maintained across the compressor, which result in high outlet temperatures. These technical difficulties can be overcome by designing compressors for this specific application. Water has excellent environmental and safety features, i.e. it has no Ozone Depleting Potential and no Global Warming Potential and is also non- flammable and non- toxic and is available easily at low cost, hence water (R718) is amongst the earliest natural refrigerants being used for refrigeration applications. (Singh. R, Agrawal. A, 2013) (Ministry of Environment, Denmark, 2012)

- **Air**: Air is a natural refrigerant but the efficiency of the refrigeration cycle using air is very low and it cannot compete with conventional refrigeration systems. For this reason, air is used as a refrigerant across niche markets. The most common application of the refrigeration cycle with air as a refrigerant is the air conditioning of aircraft. The jet engines provide compressed air at optimum pressure resulting in light running gear. Air as a refrigerant is perhaps, not being used in any other market. However, is being tested for use in the air conditioning of rail carriage and for low temperature freezing. The concept for using air as a refrigerant for cooling purposes is fairly simple but because of the low efficiency, it is unlikely that the building industry would accept it on a large scale (Pearson. S. F, n.d.).

Currently, these refrigerants are not used in India on a mass scale owing to market barriers, but eventually would be part of the mainstream under the Montreal Protocol, especially since conventional refrigerants pose a serious threat to the environment and their increased growth will inevitably lead to catastrophic climate change. Currently, India is amidst a HCFC phase-out plan and the industry is adopting HFCs as the substitute. The developed countries are done with the HCFC phase out and after it was discovered that HFCs too have a high GWP; negotiations pertaining to HFC phase out under the Montreal Protocol are ongoing. India, however, can shift directly from using HCFCs to natural refrigerants by “leapfrogging” the use of HFCs altogether. This leapfrogging will be possible only if inexpensive technologies supporting the use of natural refrigerants are made available in India and all the stakeholders in the process are made aware of the same (Borgford-Parnell. N et al, 2015; Bhushan. C, 2015).

1.2.2 Compatible Technologies

Several technologies are currently available that adopt natural refrigerants within industrial sectors. Some of these technologies are discussed below:

Vapor Absorption Systems: Absorption chillers are different from the more predominant compression chillers in that the cooling effect is driven by heat energy, rather than mechanical energy. The ammonia-water system uses water as an absorber and ammonia as the refrigerant (The New Building Institute, 1998). The biggest point of interest for the ammonia-water solution is that water has extreme proclivity towards ammonia and it can be dissolved in ammonia in various working conditions, also the solution is non-corrosive and can be employed with various materials.

Cascade Systems: The cascade system is an alternative to a single-refrigerant system, and is used extensively in the food refrigeration industry. A cascade system is made up of two separate but thermally connected refrigeration systems, each of which has a primary refrigerant. The refrigerants work in concert to reach the desired temperature, which can sometimes be as low as -100°C in bio-medical applications (Heaney. C et al, 2007) A typical circumstance is utilizing carbon dioxide as the 'low stage' refrigerant working together with a fluorocarbon, a hydrocarbon or alkali as the 'high stage' refrigerant.

Secondary Loop Systems: A secondary loop system is made up of two refrigeration circuits or 'loops', working together as a single system. One loop uses a primary refrigerant, and the other uses a secondary refrigerant. The primary system has all the same features as a single loop system – the difference is that, at the evaporator, instead of exchanging heat with the space that is being cooled, heat is exchanged with the secondary refrigerant, which in turn is removing heat from the space (Heaney. C et al, 2007).

There are various commercial applications of the secondary loop system, for example, supermarket refrigerators, commercial AC units etc. air conditioners and various other systems. Usually, the second refrigerant employed is non-toxic. Advantages of this system are:

- These systems are safer as non-toxic secondary refrigerants are used.
- The amount of primary refrigerant is reduced leading to lesser costs and environmental degradation in case of fluorocarbons.
- The control systems become very simple and the maintenance costs are reduced.

Stationary Air Conditioning: The domestic and commercial sectors are the ones where majority of the stationary air conditioning systems are used. All over the world, demand for cooling in these two sectors is growing at an exponential rate with the ever increasing temperatures. Given the harmful effects of the conventional refrigerants to the environment, natural refrigerant alternatives are available for the stationary air conditioning and are undergoing a lot of research and developments. Following are the various sustainable technologies available for stationary air conditioning which make use of natural refrigerants (Maté. J and Papathanasopoulos. C, 2012):

- **Air Conditioning System Using Propane (R290):** Hydrocarbons are getting more and more recognition in domestic and commercial cooling systems. Now hydrocarbon chillers are available up to 1000kW for commercial use. In India, for the domestic air conditioning sector, Godrej & Boyce, in 2012, launched a split type air conditioner in the 1 & 1.5 TR category which uses propane (R290) as a refrigerant. This new line of refrigerants was developed by Godrej & Boyce in association with German Development Agency, GIZ Proklima and is estimated to give 23% power savings (Maté. J and Papathanasopoulos. C, 2012)

- **Solar Air Conditioning:** Solar cooling technologies convert solar thermal energy directly into cooling power by means of thermally driven chillers. The combination of the solar thermal energy and the natural refrigerants make the perfect business case for sustainable cooling technologies. The technology used in solar cooling systems is sorption technology, it can either be absorption or adsorption in which ammonia or water is used as refrigerant. In the refrigeration cycle, in place of a compressor, a combination of absorption/adsorption and generator is used which converts the gas at low pressure to high pressure using hear instead of using electricity. This heat is obtained from the solar thermal energy as it is a sustainable and cost effective source of heat (Maté. J and Papathanasopoulos. C, 2012)
- **Evaporative Cooling:** The evaporative cooling technology works on the same principle as the perspiration of our body. When dry air comes in contact with water, some of the water in the liquid state evaporates into vapor state and in this process heat is taken away from the dry and hot air leaving it cool and moist. The principle behind evaporative cooling is that there is heat transfer due to the endothermic evaporation of water (AESC, n.d.).

There are 3 types of evaporative cooling:

1) **Indirect evaporative cooling:** Air from outside enters the system and its temperature is reduced without increasing the relative humidity as it is passed through the dry part of the opening. Outside air is cooled without gaining moisture as it is passed through the dry section of an evaporative cooling heat exchanger. Energy efficiency is increased by passing pre-cooled air through the system.
2) **Direct evaporative cooling:** In the direct evaporative cooling technique, the hot and dry air passes through the wet media converting it into cool air with added humidity. This technique is used for pre-cooling the air for the vapor compression cycle for increasing efficiency.
3) **Indirect-direct evaporative cooling:** Direct evaporation is used for cooling the ambient air before it enters the condenser coil and the while indirect evaporation is used for cooling the make-up air through the heat exchanger.

Mobile Air Conditioning: In India, the number of automobiles manufactured is increasing and the percentage of air-conditioned models was 65% in 2002-04, which increased to 100% in 2011-15. Also, nearly every automobile which is manufactured or sold, the refrigerant used in the air-conditioning is HFC-134a and it has a GWP of 1430. The climatic and high traffic conditions in India are such that the average amount of fuel required by the mobile air conditioning can go up to 20%, so if we install energy efficient systems, there will be more saving the India. The automobile air conditioning sector in India has phased CFC-12 out completely to use HFC-134a, however due to the GWP of HFC-134a, the manufacturers are considering switching to HFO-1234yf. As of now, there is not a single HFO-1234yf manufacturer in India as the technology is patented by the developed countries and the supply of the refrigerant is uncertain and costly. The automobile market in India can shift to using HFO-1234yf only if market drivers like strict standards, government subsidies or demand from the consumers are introduced.

To replace HFC-134a, the feasible options available in the market are: HFO-1234yf (GWP = 4), HFC-152a (GWP = 138), and CO2 (GWP = 1) (IPCC Fifth Assessment Report, 2014). The reason for exclusion of hydrocarbons as a refrigerant is not the lack of performance, but the safety concerns as hydrocarbon refrigerants are flammable (NRDC, 2013). The replacement of the refrigerant leads to increase in the overall system cost in the following way:

- **HFO-1234yf**: HFO-1234yf is the closest and most efficient alternative to HFCs which needs trivial changes in the existing models of equipment. The major drawback of HFO-1234yf is that due to its tedious manufacturing process, its current price is almost five times as the conventional refrigerants, resulting in increased cost of the air conditioning system.
- **CO2:** The operating pressures for CO2 as a refrigerant is very high and needs advanced components entirely. Hence even if the price of CO2 is lower than HFC-134a, the overall cost of the system increases due to increased cost of the components.
- **HFC-152a**: The price of HFC-152a is lesser than HFC-134a but the systems using HFC-152a as a refrigerant need to have an additional cooling cycle to prevent the refrigerant from entering the car as it is flammable. Hence the cost shoots up.

Radiant Cooling: In this system, the heat is removed from the roof and the floor by laying plastic pipes in loops between the slab and the tiles. The radiator cools the water which is passed in the pipes so that the structural heat load is removed, thereby reducing the cooling load imposed on the air conditioning system. This leads to significant amount of savings in the energy used up by the air conditioning without losing water. The major advantages of employing radiant cooling system are:

- The occupants in the room feel thermal comfort, as this system absorbs solar heat from the roof and reduces the air conditioning load and in some cases can completely negate the need of an AC
- Even in the hottest day of summer, the structural cooling system is able to maintain the floor temperature below human skin temperature, thus a person would feel pretty comfortable sitting and walking on such floor with bare feet
- Cooler floor and ceiling reduces the Mean Radiant Temperature, enhancing the feeling of comfort for the same temperature and humidity
  The heat is removed at a higher temperature (about 25 deg C) rather than 10 deg C by the chiller. The power consumption is much lower as the temperature at which water is condensed is the same.

Structure Cooling: The ancient Indian architecture has provided us with many strategies for cooling the interiors of structures by adding features to the design of the building. By the use of structure cooling, Mean Radiant Temperature of the rooms in reduced, thus ensuring thermal comfort of the occupants. The structure cooling works on three basic principles:

- Thermal Barriers: This principle says that barriers should be created against sunlight in the form of hollow walls, trees, or shading devices. The barriers act as resistors to the incident heat and help in reducing the temperatures.
- Mass as Heat Sink: The thick walls don’t let the heat to be transmitted to the inside of the building, thus acting as a capacitor. In the day, the walls absorb heat without much change in the interior temperature and during the night, it radiates the heat back to the atmosphere.
- Heat Drainage: The residual heat should be channeled to be drained out into flowing water or flowing wind during the night for preventing the interiors to heat up.

This technology is similar to Radiant Cooling technology, but chilled water may not be used. Water is drawn from a storage tank and allowed to flow through pipes (embedded in slabs) in direct contact with the surface of the structure. Water absorbs heat from the structure and flows back to the tank again, where it gives away the heat gained. The cooling of this water in the tank requires radiators (heat exchangers) in bigger applications. Polypropylene pipes (corrugated) are generally used. This technology reduces heat ingress and keeps the room temperature from rising too high, thereby reducing the cooling requirement of the building significantly. Pumps are the main power consumers in this system. Structure cooling is generally used in conjunction with active Air-conditioning systems (Cooling India, 2013).

1.3 Economic Implications

The uptake of natural refrigerants and technologies in India not only holds an environmental and social advantage, additionally, there exists a strong business case for phasing down the use of HFCs. In India, for example, energy efficient R290 (GWP < 5) based air conditioners are already being manufactured by Godrej and Boyce, highlighting the fact that the technology already exists and is in use on a smaller scale. What needs to be addressed are the economic feasibility and implications of such a transition to natural refrigerants. Major chunk of HFC used will be used in the air conditioning sector (stationary and mobile), and in 2030, the number of room air conditioners is expected to increase by almost 30 times as compared to that in 2010 (NRDC, 2014). So it is evident that manufacturing systems which use R290 as a refrigerant will not only be economically viable but have a much lower GWP.

Economic Implications of climate change

On the global scale, if we concentrate only on mitigation of CO_2 and ignore emissions from HFCs, they could amount from 28 to 45% of the total GHG in the atmosphere by 2050 (Velders et al, 2009). These emissions can translate into catastrophic results especially for developing countries that are highly vulnerable to climate change impacts, where these impacts will translate into huge economic losses for India. Agriculture sector, for example, will face severe production losses, where rice, wheat and maize are estimated to face production losses of around US$ 208 Bn and US$ 366 Bn in 2050 and 2100 respectively. Another sector that would potentially be severely affected due to climate change would be the power sector, where additional power generation capacity may need to be installed. Capital investments required are estimated to be around US$ 33 Bn and US$ 123 Bn in 2050 and 2100 respectively for satisfying the increased cooling needs of India. To save on these costs and impacts from climate change, a transition to sustainable cooling technologies will be a more feasible option (Chaturvedi. V, 2015).

Implications of increasing uptake of natural refrigerants across cooling technologies

1.3.1 Energy efficiency

The use of natural refrigerants in refrigeration and air conditioning systems, according to system specification, could prove to be 40% more efficient as compared to HFCs. These reduced costs are realized in mid to long term due to reduced operation costs (Greenpeace, n.d). In India, energy consumed by air conditioning systems rose from 2,308 GWh in 2006 to 5,099 GWh in 2011, and this is the largest chunk of overall power consumed in the residential sector (NRDC, 2014). In this scenario, using natural refrigerants provides a two-fold benefit: reduction in the energy cost and protection of the environment through negligible or zero GWP and ODP.

- **Ammonia:** Vapor absorption systems have been operation on ammonia as refrigerant for decades on account of its brilliant thermodynamic attributes, resulting in 3% to 10% higher system efficiency than that of HCFC-22 and HCFC134a. In industrial systems having capacities more than 500 kW, ammonia is simply unsurpassed in terms of energy and cost efficiency. Its uptake has been increasing on a smaller scale, for example in systems with a capacity of less than 500 kW where the quantity of ammonia can be reduced when choosing a suitable secondary refrigerant (Witt. M, n.d.). Recent developments towards combining NH3 and CO2 resulted in an increase in efficiency even further. NH3/CO2 cascade is proven to be very efficient for low and very low operating temperature applications (below -40OC), while NH3/CO2 brine systems are around 20% more efficient than traditional brines (Danfoss, 2016).

- **Carbon Dioxide**: Carbon dioxide has recently been rediscovered as a feasible primary and secondary refrigerant. As compared to Ammonia, large food processing and storage plans which used CO2 as a refrigerant is estimated to result in 29% more cost saving. Majority of applications for CO2 are as a low temperature refrigerant and in cascade systems. The cascade systems use ammonia in the high stage and CO2 in the low stage. The energy efficiency of CO2 systems can be similar to that of HCFC-22, ammonia and R-410A in the evaporator range of –40°C to –50°C. CO2 is also being used as an indirect system heat transfer fluid (Devotta et al, n.d.; Sustainability Victoria, 2009).

- **Hydrocarbons:**

    - R290: Propane or R290 exhibits higher energy efficiency in the regions having higher temperature. As, R290 has higher volumetric efficiency, the energy efficiency achieved by it is comparable to the conventional refrigerants, therefore R290 potentially offers notable benefits in terms of compressor reliability, especially in hot climates. Although the cycle efficiency of R290 is almost equal to that of R22, the thermo-physical properties of R290 provide advantages in the life cycle performance of the refrigeration system (Colbourne. D, 2011)
    - R600a: Isobutane (R600a) has been successfully used in the domestic refrigeration sector since 1992 and it is evident that the technology which makes use of R600a is more safe, energy efficient and less noisy than the fluorocarbon counterparts (Cox. N, 2011). The COP of R600a is about 3% more than the COP of R134a which makes R600a more energy efficient than its counterpart (Qureshi. A and Bhatt. S, 2014; Baskaran. A and Mathews. K, 2012).

1.3.2 Direct Refrigerant product cost

The direct refrigerant product cost for the natural refrigerants except R290 is usually very low as (seen in *Table 2*), because they are naturally occurring substances and can be produced very easily in an inexpensive manner. Moreover, their availability is not known to be an issue since under most cases they are by-products of various industrial processes.

- **Ammonia:** Ammonia is considered as the most cost efficient industrial refrigerant from the operations points of view, hence the end cost to the customers for food remains low. In India, as per the table below, the average cost of ammonia is Rs 55.2/kg, which is very low as compared to HCFCs and HFCs. As the production and purification process of ammonia is not very complex, it is produced at low costs and available all over the world. Hence, cost of ammonia itself is significantly less than other industrial refrigerants and comparatively, lesser amounts of ammonia is required to do the same job as other industrial refrigerants. All of this adds up to lower operating costs for food processors and cold storage facility operators (IIAR, n.d.).

- **Carbon Dioxide:** Carbon dioxide is an inexpensive refrigerant as it a by-product of various industrial processes. The production process of CO_2 is very simple and does not include any IPR charges hence the production cost of CO_2, Rs 22/kg on an average in India is also very less as compared to the conventional refrigerants. This result in reduced operating costs and the refrigerant is economically and easily available (Danfoss, n.d).

- **Hydrocarbons:** The production of propane (R290) is a simple and inexpensive process as it is a commonly available by-product from gas processing plants, thereby, reducing the operational cost of the refrigeration system to a great extent as compared to the conventional refrigerants. India's domestic chemical manufacturers should be able to produce R-290. Liquid petroleum gas (LPG) producers and refineries are often capable of supplying refrigerant-grade R-290 (NRDC, n.d).

Table 2 | Direct Refrigerant product cost

		Price (per kg)		
Refrigerant Type	Refrigerant	Minimum	Maximum	Average
HCFC	R22	390	590	466
HFC	R134a	395	470	416
	R404	385	470	436
	R407c	460	470	465
Azeotropic Blend	R410a	385	470	428
HC	R290	1,725	4,200	2,570
Natural Refrigerant	R744	20	25	22
	R717	41	65	55.2

Source: Based on the data collected from refrigerant dealers and manufacturers by cBalance, 2016.

1.3.3 Direct Equipment cost

The major cost related to the adoption of natural refrigerants is the initial, equipment change or the retrofitting cost. As in the case of natural refrigerants, safety is of utmost importance due to toxicity and flammability concerns. Further, there is a need of additional systems and components to take care of that resulting in increased initial investment.

Ammonia: Ammonia as a refrigerant is economical and liberally accessible; however, the retrofitting or installation of the refrigeration systems and ammonia chillers is comparatively expensive owing to the fitting of steel tubes, semi-hermetic compressors and use of various safety equipment (Refrigerants.danfoss.com, 2016). The estimated capital cost for the initial installation of ammonia chillers is 250% of the fluorocarbon counterpart units. However, cost of the ammonia chiller over its complete lifecycle is much lesser owing to lower operation and recharging costs. (Heaney. C et al, 2007; Rolfsman. L, 2005; Mundie. I, 2005) Ammonia's pungent odour acts as a self-alarming characteristic, due to which even very low amounts of the refrigerant leaks can be detected, allowing immediate and mechanical repair of the leaks in the system. These safety features lead to the added cost of the equipment for ammonia as compared to the conventional refrigerants (Danfoss, 2016; IIAR, n.d).

Carbon Dioxide: CO_2 can be employed commercially towards 3 types of refrigeration systems:

- Subcritical (cascade systems)
- Trans-critical (CO_2 -only systems)
- Secondary fluid (CO_2 used as volatile brine).

Carbon dioxide as a refrigerant, costs very less, however, CO_2 refrigeration systems are more expensive in comparison to the conventional refrigeration systems, since the system operates at higher pressures and is more complex in the trans-critical and sub-critical scenarios. As the booster systems are introduced in the market, complexity of CO_2 refrigeration systems reduce, giving way to decreased system costs and increased number of CO_2 system installations (Refrigerants.danfoss.com, 2016). For e.g. Sobeys, which is a supermarket store in Quebec, Canada has installed transcritical refrigerant systems using CO_2 as a refrigerant. They claim that the initial cost for the equipment for CO_2 transcritical refrigeration systems incurred by them was 11% more than the traditional HCFC DX, but at the same time the installation cost was reduced by up to 15%, while maintenance cost was reduced by 50%. They further calculated a payback time of 3 years for the complete setup (UNEP, 2014). Large industrial refrigeration system, in which CO_2 is used as a secondary fluid, is less expensive to build than the conventional systems, and thus involve lower initial investments. The technology used depends on the application and the location of the system (Danfoss, 2016).

Hydrocarbons: The volumetric capacity achieved by Propane (290) as a refrigerant is almost same as that of CFCs; hence the initial costs of retrofitting or retooling of the equipment are avoided. Godrej and Boyce in has been producing and selling R290 based air conditioners in India since 2012. The market price of Godrej Eon air conditioner is Rs 33,000 which includes the installation charges by qualified and certified technicians. The price of the equipment is marginally more when compared to the price of a comparable air conditioner using R22 as a refrigerant at market price of Rs 31,000 (Hydrocarbons21, 2012).

1.4 Social Implications

Modernization of the food industry and changing lifestyles, especially in developing economies such as India and China, have led to the global refrigerant market to grow to $21 billion and the refrigeration equipment market to $38 billion by 2018 (Reportlinker, 2014). The Indian air conditioning and refrigeration market is expected to grow by up to 20% in the coming years as major reforms are introduced towards strategies and plans across the infrastructure development sector. Knowing that there is a rise in the income of the middle class in India and factors like increasing temperatures in the existing hot and humid climate and adoption of higher standards of living, the use of air conditioning and refrigeration systems has expanded manifolds. These systems can have a major impact on India's GHG emissions due to direct refrigerant leakage and through indirect emissions from energy consumption.

An amendment within the Montreal Protocol mandated that parties need to phase out use of HCFCs by 2030. As HFCs have zero Ozone Depletion Potential (ODP), they are the most favorable substitutes to HCFCs. However, it is established that HFCs have a very high Global Warming Potential (GWP) and in the coming decades they would contribute significantly to climate change. Based on this finding, another amendment was proposed that mandated parties to phase out use of HFCs over the coming decades. For six years, it seems that India has been trying to buy more time towards the HFC phase out plan since the alternatives to HFCs were either costly, because they were patented (for example, HFO-1234yf refrigerant) or untested for safety (Sethi. N, 2014).

In April 2015, during the 35th meeting of parties to the Montreal Protocol, India submitted its HFC phase out proposal which suggested that India would freeze its HFC production and consumption from 2031 and complete the phase out by 2050. The amendment also specifies a demand for full compensation towards the transition as well as towards the reduced profits incurred by gradual closure of existing plants using HFCs (T. V. Padma, 2015; MoEF&CC, 2015).

As of now, in India, the use of CFCs has been completely phased out and HCFCs are the dominant refrigerants in the market. Analysts suggest that Indian manufacturers can leapfrog directly from using HCFCs as refrigerants to climate friendly technologies to avoid multiple changeovers in the technologies. The main glitch in doing this is that the cost of these technologies is very high, for example, in the automobile air conditioning sector; the technologies for the use of HFOs are being used in the developed countries but are patented and expensive. India's environment minister, Mr. Prakash Javadekar, presented these issues in the 36th meeting of the Parties to the Montreal Protocol at Paris, so that they can be addressed before finalizing the agreement. Patents, intellectual property law, and other confidentiality agreements prevent India and rest of the developing countries from making full use of new technology, and also that developed countries like the United States are traditionally accountable for the vast majority of HFC emissions. Hence India would seek minimum 15 years of "grace period" for differentiated responsibility, financial assistance, including that for research and development and free technology transfer (Spross. J, 2014).

The economic power is clustered with few of the companies in the developed nations through the possession of patented technology and intellectual property rights but what is to be understood here is that the whole world is facing the effects of climate change. India being a highly cost sensitive market, the expensive technologies will not be able to reach the masses and the phase out plan will be unable to achieve the required speed and intensity (Datta. A, 2014).

India's HVAC industry's worth was INR 25,000 crores and the Refrigeration industry's worth was INR 8,000 crore in 2014 and is predicted to witness exponential growth in the years to come (Ram. N, 2014). The growth of the HVAC & R industry is because of two emerging sectors; first is the smart buildings sector which growing at a CAGR of 30% and the second is refrigeration and cold chain industry which is growing at a CAGR of 25% resulting in increased employment opportunities in the years to come (ACREX, 2016).

Government of India has operationalized various schemes and initiatives which will directly or indirectly help creating jobs for the skilled as well as unskilled laborers. The first and the largest scale initiative is the Make in India movement which permits 100% FDI in various sectors, such as food processing, automobile, chemicals, electrical machinery and tourism and hospitality (which are all directly linked to the refrigeration and air conditioning industry), will ensure the number of employment opportunities. The total employment generated in the Make in India sectors was 39.66 million in 2004-05 which increased to 104.89 million, i.e. by 164 per cent in 2011-12, mainly due to the big jump in the construction sector (CII, n.d.). The booming construction sector will definitely give way to increased refrigeration and air conditioning applications.

The Skill Development Initiative Scheme by the Government of India aims at training school dropouts and employees working in the unorganized sector for employable skills. In close consultation with industries/State Governments and experts the scheme has been brought into operation (MSDE, 2016). The scheme aims towards mental development of the youth of India right from school level by increasing their confidence, thereby improving their productivity. This is not only important for economic development of the country but will help to fulfill dreams of the youth for good quality of life, better jobs and avenues for self-employment (MSDE, 2015). Uptake of natural refrigerants and sustainable cooling technologies will give way to further opportunities in this industry over the entire value chain of refrigeration and air conditioning services. Right from research and development of energy efficient technologies, manufacturing of equipment, HVACR consulting, project management, and various support services like installation and commissioning, operation and maintenance, plumbing, electric services will have increased employment potential.

Moreover, development of over 100 smart cities would perhaps result in a tremendous growth across the air conditioning and refrigeration sectors. The development of smart cities will take place through comprehensive expansion under the four supporting pillars: "institutional infrastructure, physical infrastructure, social infrastructure, and economic infrastructure". Under the "Housing for All" scheme, GoI has set a target of developing 60 million houses, of which 40 million will be in rural area and 20 million in urban area, by 2022. These houses are planned to possess "smart" systems in terms of cooling and heating, suggesting a great potential for applicability of sustainable cooling technologies such as structure cooling as well as use of natural refrigerants. Initiatives undertaken by the government such as "city challenge" would enable fast track and efficient development through retrofitting of existing equipment, redevelopment of entire facilities and green field development of urban areas which can enable incorporating sustainable cooling technologies in the residential, commercial and transport sector. Demand for energy efficient and environment friendly technologies in India will be huge giving way to increase in uptake of natural refrigerants and related technologies, increasing the scope of job opportunities in the sector (FICCI & PWC, 2015; Smartcitiesindia.com, 2016).

The air conditioning and refrigeration industry suggests a tremendous potential for improving the efficiency of cooling systems resulting in almost 40% energy savings. Additionally, it is an established fact that systems using natural refrigerants are more energy efficient at higher ambient temperatures, i.e. 350 C, prevailing in India (Phadke et al, 2014). Energy saving is not the only cost saving mechanism for operators, as on a larger scale it relieves the energy sector from the ever increasing peak demands in which air conditioning and refrigeration sector plays a significant role, and reduces demand for the capital intensive power plants. In India, most of the infrastructure expected to exist in 2030 is yet to be built; hence there is tremendous potential for adoption of sustainable cooling technologies which will result in energy savings of almost 60 GW at peat time by 2030 (McKinsey and Co., 2009). The saved energy in a sense then delivers nega-watts, which will facilitate provision of electric power in electricity deficient rural areas and help in improving the quality of life and bridge the gap between development in the rural and urban area. Access to electricity for the deprived population will result in higher education and earning power, and increased productivity. There are many secondary advantages for increasing the human development like increased access to health services, access to information, cleaner environment and overall empowerment of the society (WHO, 2003).

Unrestricted use of conventional refrigerants would contribute significantly to climate change, eventually resulting in catastrophic events such as, ‘floods, extreme heat waves, crop failure, rising sea levels, decreasing water tables and draughts, with low-income countries at maximum risk. As a majority of population in India is highly dependent on sectors sensitive to climate change impacts, for example, agriculture, natural ecosystems, energy, water, energy etc. Therefore, impacts from climate change would result in massive loss of property and life, moreover, would impose long term health impacts due to increased production of certain allergens and air pollution. Studies have revealed that if ambient global temperature increases, there will be increased distribution of some vector organisms, for example Malaria mosquitoes and result in increased exposure to such vector borne diseases. There is a significant financial, technological and institutional gap in climate change adaptation needs in India. Climate change has started to affect around 800 million people and there is a requirement of $1 trillion till 2030 for India to adapt to climate change impacts (Garg A et al, 2015). These adaptation gaps and increase in effects of climate change will lead to migration of affected people to the lesser affected areas. The reasons for climate migration can be reduced agricultural potential of the area, increased frequency and intensity of extreme weather events or increasing sea level in coastal and low lying lands (Panda A, 2010). Erosion of the Brahmaputra river basin has forced about a million people to relocate due to increased floods every year. The accommodation of these climate refugees pose an additional responsibility on the already resource stressed cities where they migrate in search of jobs and shelter (Gupta J, 2014).

In 2014, Micro, Small and Medium Enterprises (MSMEs) made up 8% of India’s GDP and this segment is expected to grow to 15% by 2020, proving MSMEs to be one of the most thriving segments of Indian economy (CII, 2014).

As of 2014, the employment rate under MSME was 28%, and as the MSME sector grows, the employment contribution is expected to grow over 50% in the next 10 years. The advantage of encouraging MSME is that large scale employment can be generated at lesser initial cost and the employment opportunities can be provided to rural and unskilled labour, by working as a support system to large enterprises. (KPMG, 2014) The growth and employment opportunities for the sectors that are closely related or dependent on the refrigeration and air conditioning sector are mentioned below:

Table 3 | Sector wise employment opportunities in HVAC & R

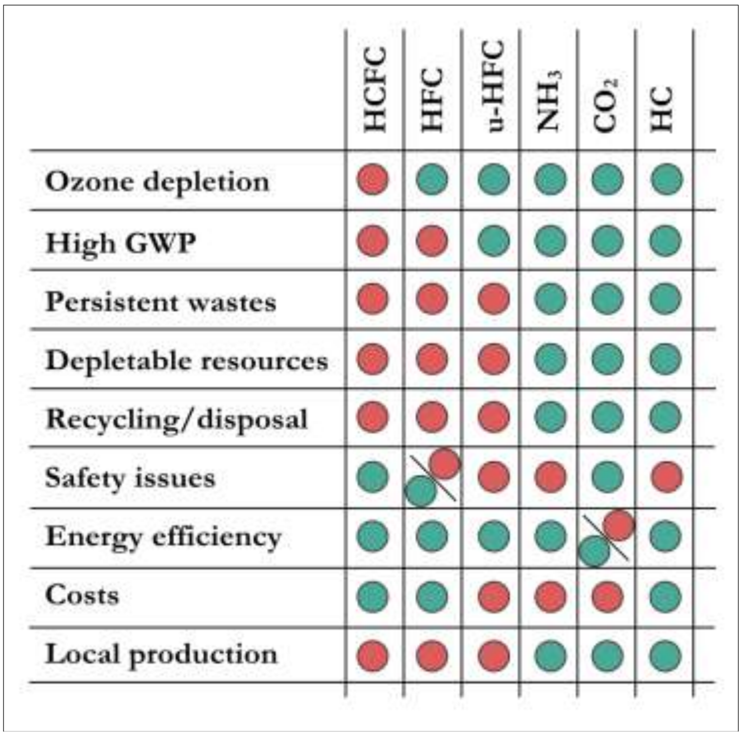
Sr. No.	Sector	Sector Size		CAGR till 2020	Employment in 2014 (millions)	HVAC&R Employment Opportunities
		2014	2020			
1	Automotive	400	670	9%	19	• Mobile Air Conditioning refrigerant and equipment production and maintenance
2	Transport and Logistics	610	1140	11%	16.6	• Development of airports in tier 2 and tier 3 cities • Ports and port services • Green Supply chain
3	Industrial Manufacturing	700	1540	14%	2	• High precision manufacturing • Manufacturing under sensitive conditions • Sustainability and pollution management
4	Food and Agriculture	1590	1790	2%	238	• Packaged food and diary sector • Backend infrastructure of cold chains
5	Retail	2610	3700	6%	28	• Cold supply chain and packaged foods
6	Real Estate	305	570	11%	33	• Heat ventilation and air conditioning consultants and services

Source: The new wave Indian MSME: An action agenda for growth, KPMG, Pg 6-8
[Transport and Logistics, (McKinsey, n.d.); Industrial Manufacturing (DHI, 2014); Food and Agriculture (MoF, 2014); Retail (Ernst & Young & RAI, 2014); Real Estate (McKinsey, 2009)]

1.5 Environmental and Safety Implications

Most refrigerants do not come without either environmental or safety implications, these properties are mentioned in *Figure 20*.

Figure 20 | Refrigerants' comparison



Source: (GIZ Proklima, n.d.)

The table lucidly illustrates that natural refrigerants have zero or negligible impact towards the ozone layer, this is also corroborated by and can be seen in *Table 4*. Moreover, natural refrigerants are made available through local production, can be recycled and disposed safely. However, for Hydrocarbons, owing to their flammable nature, safety systems have to be elaborate, however, it is possible to use Hydrocarbons are refrigerants safely across all the sectors (GIZ Proklima, n.d.).

1.5.1 GHG Emissions

Conventional refrigerants largely affect the environment through two ways: As a result of their Ozone Depleting Potential (ODP); and the refrigerants containing Chlorine (CFCs and HCFCs) deteriorate the ozone layer through the chemical breakup of ozone molecules in the stratosphere. This is known as the ODP and is benchmarked against the ODP of the Trichlorofluoromethane (CFC -11, also known as R - 11) which is fixed at 1. Simply put, depletion of global ozone layer caused by a unit mass of a particular refrigerant relative to that of R11 is defined as ODP of the refrigerant. Ideally, a refrigerant should have an ODP of less than 1. Primarily, CFCs and HCFCs have the highest ODP and are largely responsible for the ozone layer depletion, their phase out is essential (ASHRAE, 2012).

Conventional refrigerants once leaked into the atmosphere have a tendency to cause a greenhouse effect and pose a significantly high Global Warming Potential (GWP), GWP of HFCs is amongst the highest. GWP of refrigerants is benchmarked against the GWP of CO_2 which is fixed at 1 over a 100-year period. In other words, it is the amount of heat trapped by one-unit mass of the refrigerant compared to the amount of heat trapped by an equivalent mass of CO_2. Lower the GWP, better it is for the environment.

ODP and the GWP are good indices to gauge the impact of the refrigerants on the environment when they are released/leak into the atmosphere.

Table 4 | Refrigerants and their GWPs

Refrigerant	Type	ODP	GWP (100 years)
R410A - R32:R125 50:50	F-gas	0	2088
R22	F-gas	0.055	1810
R134A	F-gas	0	1430
R32	F-gas	0	675
HFO 1234yf/ze	F-gas	0	4-6
R290 - Propane	Natural	0	3.3
R1270 - Propylene	Natural	0	1.8
R744 - Carbon Dioxide	Natural	1	1
R717 - Ammonia	Natural	0	0

Source: cBalance (2016), National Refrigerants (2016)

As seen in *Table 4*, natural refrigerants have lower ODP and GWP when compared with conventional refrigerants, therefore, fare far better than F-gas refrigerants, both in terms of GWP and ODP. Natural refrigerants would thereby be better placed for climate/ environment related regulatory compliances. Moreover, they are sustainable and compliment climate change initiatives taken up at national and global level.

The uptake of sustainable cooling technologies in the residential and commercial sector in India can result in up to 60 GW of energy savings by 2030 creating the potential to avoid the construction of about 100 medium size, coal fired power plants (McKinsey and Co., 2009). This will save the emission of 3 major GHGs in the atmosphere i.e. carbon dioxide, sulphur dioxide and nitrogen oxides, emitted during production of electricity, not to mention the additional emissions due to mining, processing and transportation of coal will also be avoided (US EPA, 2007).

1.5.2 Energy Efficiency

The air conditioning and refrigeration industry is highly energy intensive and an increase in efficiency across cooling systems will help the operator to save money and at the same time reduce the burden on the energy sector. Energy efficiency of a refrigerant is measured by its Coefficient of Performance (COP). COP illustrates the energy efficiency ratio (EER). i.e. the ratio of cooling output (kw) to the cooling input (kw). Therefore, refrigerants with a high value of COP are more energy efficient than the one's with a lower value of COP.

Table 5 | Refrigerants and their COPs

Refrigerant	Type	COP
R410A - R32:R125 50:50	F-gas	3.96
R22	F-gas	4.23
R134A	F-gas	4.6
R32	F-gas	3.98
HFO 1234yf/ze	F-gas	4.30
R290 – Propane	Natural	4.28
R1270 – Propylene	Natural	4.21
R744 - Carbon Dioxide (transcritical heat pump)	Natural	5.05
R717 – Ammonia	Natural	4.77

Source: cBalance (2016), National Refrigerants (2016), (Danfoss, n.d.; Ansbro. J, n.d.; Austin and Sumathy, 2011)

As can be observed from the *Table 5* above, there is no significant difference between the COPs of conventional and natural refrigerants. COP of natural and conventional refrigerants chosen above range from 3.96 to 4.30.

1.5.3 Toxicity

Refrigerants used before 1930s were highly toxic and flammable, however, with the commercialization of CFCs a new era of safety commenced. Currently, reason behind promotion of natural refrigerants is environmental protection and hence, safety systems need to be elaborate and their toxicity has to be taken into consideration.
Refrigerant toxicity is classified under two groups (ASHRAE, 2008; IIF, n.d.):

- Class A signifies refrigerants for which toxicity has not been identified at concentrations less than or equal to 400 ppm
- Class B signifies refrigerants for which there is evidence of toxicity at concentrations below 400 ppm

Refrigerants with classification 'A' are thus preferred.

Table 6 | Refrigerants and their toxicity class

Refrigerant	Type	Toxicity Class
R410A - R32:R125 50:50	F-gas	A
R22	F-gas	A
R134A	F-gas	A
R32	F-gas	A
HFO 1234yf/ze	F-gas	A
R290 – Propane	Natural	A
R1270 – Propylene	Natural	A
R744 - Carbon Dioxide	Natural	A
R717 – Ammonia	Natural	B

Source: (Spatz.M and Minor. B, 2008; Koban. M, 2016; ASHRAE, 2008)

As seen in Table 6, there is low toxicity concern from the sample of chosen natural refrigerants as all fall under class A except for R717. It should however be noted that R717 (Ammonia) is classified as a toxic refrigerant in spite of being a naturally occurring gas, however, it is considered safe if the quantity of ammonia in the surrounding air is less than 20 ppm. The characteristic odour of ammonia can be noticed when the concentrations reach 53 ppm (A-Gas, 2005).

Continuous exposure to ammonia at concentrations of 300-400 ppm will make the occupants feel uneasy and the concentrations of 700 ppm will cause serious damage and burns to eyes. If the concentration of ammonia in the atmosphere reaches 5,000 ppm or more, it can be lethal for human beings in 5 minutes (Lindborg A, 2005; AIRAH, 2007). However, with proper safety devices and personnel training it is possible to successfully use ammonia in refrigerating systems, prevent leak and avoid accidents, which is already proven as it is being used in the real world.

1.5.4 Safety

This section elucidates on the flammability of refrigerants, i.e. their ability to catch fire at ambient temperature and pressure conditions (i.e. at 21°C and 101 kPa) as well as degree of heat of combustion released as a result.

- Class 1: No flame propagation at ambient conditions
- Class 2: Low flame propagation at ambient conditions and heat of combustion less than 19 kJ/kg.
- Class 3: High flame propagation at ambient conditions and heat of combustion more than 19 kJ/kg.

Therefore, class 3 refrigerants need very careful handling and have high safety requirements whereas class 1 are considered the safest. *Table 7* showcases refrigerants based on their flammability levels.

Table 7 | Refrigerants and their flammability class

Refrigerant	Type	Flammability Class
R410A - R32:R125 50:50	F-gas	1
R22	F-gas	1
R134A	F-gas	1
R32	F-gas	2
HFO 1234yf/ze	F-gas	2
R290 – Propane	Natural	3
R1270 – Propylene	Natural	3
R744 - Carbon Dioxide	Natural	1
R717 – Ammonia	Natural	2

Source: (Spatz. M and Minor. M, 2008; Koban. M, 2016; ASHRAE, 2008)

As can be observed, there is no clear distinction on safety levels for the natural refrigerant sample compared to the f-gas refrigerants. On categorizing the most commonly used natural and F-gas refrigerants on the basis of their environmental and safety aspects, it can be concluded that natural refrigerants fare far better in their ecological impact due to low ODP and GWP, but their flammability is a major concern, that is addressed in the following section.

1.5.5 Safety Considerations of R290

In case of R290, safety is of paramount consideration as it belongs to a safety group of 3 and is a highly flammable, colourless, odourless and non-toxic gas. It has a lower explosive limit of 2.1% and upper explosive limit of 9.5%. The flash point is below the atmospheric temperature and exposure to atmosphere in combination with spark/flame/hot surfaces may cause fire immediately. It spontaneously forms an explosive air-vapour mixture at ambient temperatures and as its vapour is heavier than air, it may even travel to remote sources of ignition (e.g. along drainage systems, into basements etc.).

The safety of the R290 systems can be dealt with under the following fronts:
1) During Construction / Manufacturing:

- All the tubing joints should be brazed properly and their installation should ensure that the bends or joints are not stressed.
- Since R290 is denser than air, so in case of leakage it will collect at the bottom of the enclosure thus the base is constructed in the form of a leak-proof pan so that any releases will be held within the enclosure.
- Minimum one gas sensor should be positioned inside air tight enclosure, where upon exceeding a pre-set concentration the electricity supply is isolated by the gas sensor and also a warning signal is given. Even if the total HC-290 leaked it should be made sure that the concentration is below the explosive density of R290 (43.6 to 175 g/m3).

- Electrical components like capacitor, thermostat switch, etc. should be sealed. Valves and detachable joints must not be located in areas accessible to the general public. And it should be ensured that the refrigerant charge of the system does not exceed the charge size limits.
- The system should be labelled with the type and quantity of refrigerant used in it and all the tube connections should be insulated to avoid formation of water condensation and water damage to the rooms.
- The compatibility of all the materials that are to be used within the refrigeration system (particularly valve seals, o-rings, etc.), should be ensured with the HC refrigerant to be used.

2) During Operation:

- Smoking has to be prohibited in the area where R290 systems are installed.
- The equipment should be positioned so that proper and free ventilation around all sides of the equipment is ensured, and it will not be inhibited by any permanent or temporary blockages.
- Consideration should be given to the positioning of the equipment with regards to areas where people may congregate or gather. The system should not be installed in humid places and should not be cleaned with water.
- Air Conditioner must be kept away from fire, spark with energy greater than 20mJ or hot surfaces with temperatures more than 450 deg C to prevent the ignition of R290 as it auto ignites at 540 deg C.
- In case of any irregular event, like burnt parts, smell, loud noise then the system should be disconnected immediately to isolate from electrical supply.

3) During Maintenance and Recharging:

- Regular maintenance and system checks should be carried out by trained and certified technician using standard equipment. Before servicing the system, the surroundings should be cleared off any safety hazards to ensure safe working.
- A risk assessment needs to be carried out for minimizing the risk of ignition of R-290. Storage of any combustible goods and presence of ignition sources within the working environment should be prohibited.
- At any point of time, firefighting equipment should be readily accessible.
- It must be ensured that leakages are checked and no other gases should be present in the system before recharging. The charge amount should not be exceeded and at the same time, quantity of recharging is not less than specified as it may reduce the system performance.
- Post recharge leak test should be carried out to ensure safety of the system and the occupants.

4) During Leak Repair:

- During the repair leak, the refrigerant should be removed from the system to avoid an uncontrolled discharge. The leak source should be examined and the reason of leakage should be determined. The repairs should not be on a temporary basis and quick action should be taken on the defects or shortcomings found out after the examination of the system.
- After each intervention into the refrigeration system, the system should be subjected to a leak test.

02

2 Mapping: Natural Refrigerants and Refrigeration Technologies in India

2.1 R290/Hydrocarbon

2.1.1 Current Uptake Scenario

2.1.1.1 Applicable Sectors

The hydrocarbon refrigerants in common use today (in Airconditioning & Refrigeration) are R290, R600a and R1270. Among these, R290 has a long history in refrigeration and has been in use since even before CFCs were developed, hence the technology required to use this refrigerant was already available. Apart from R290, R600a is currently being widely adopted across refrigeration. R1270 systems are yet to find space in the market. R290 has the same issues as with R1270, primarily that of flammability. Across all the HCs the above mentioned ones have been found to have the most suited thermodynamic properties for use as a refrigerant.

The R290 (Propane) refrigerant is currently being used for stationary Airconditioning and Refrigeration purposes across both, domestic and commercial sectors in India. At present, Godrej Boyce is the only manufacturer in India currently manufacturing and installing 1 TR and 1.5 TR ACs based on the R290 refrigerant. For this purpose, the study has considered statistics provided by Godrej & Boyce. Data pertaining to R290 based refrigerators was not provided.

2.1.1.2 Installed/Sold Capacity

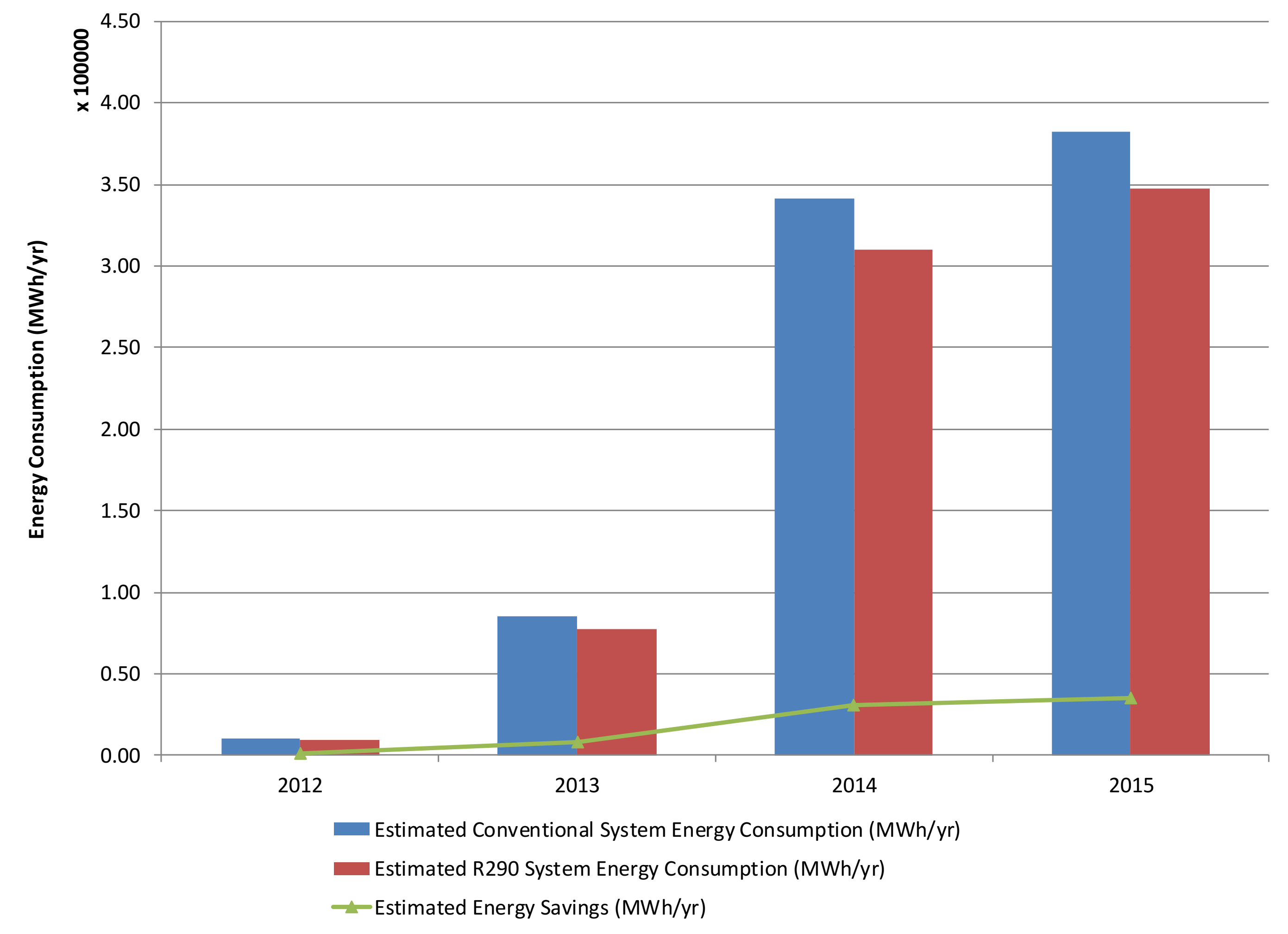
Units and Tonnage

Godrej & Boyce, since the inception of the R290 project in 2011 until 2015 had sold/installed 2,40,000 ACs, out of which 84,000 (35%) are 1 TR and 156,000 (65%) are 1.5 TR based ACs. At the start in 2012, Godrej & Boyce sold only 3,000 units (3,975 TR) increasing to 22,000 units (29,150 TR) the very next year at a growth rate of 633.33%. In 2014, the installations increased significantly by another 240.91% and reached 75,000 units (99,375 TR), and reached 1,40,000 units (1,85,500 TR) at an increase in growth by 86.67% in 2015, *as seen in Figure 23*.

GHG, Power and Energy Savings

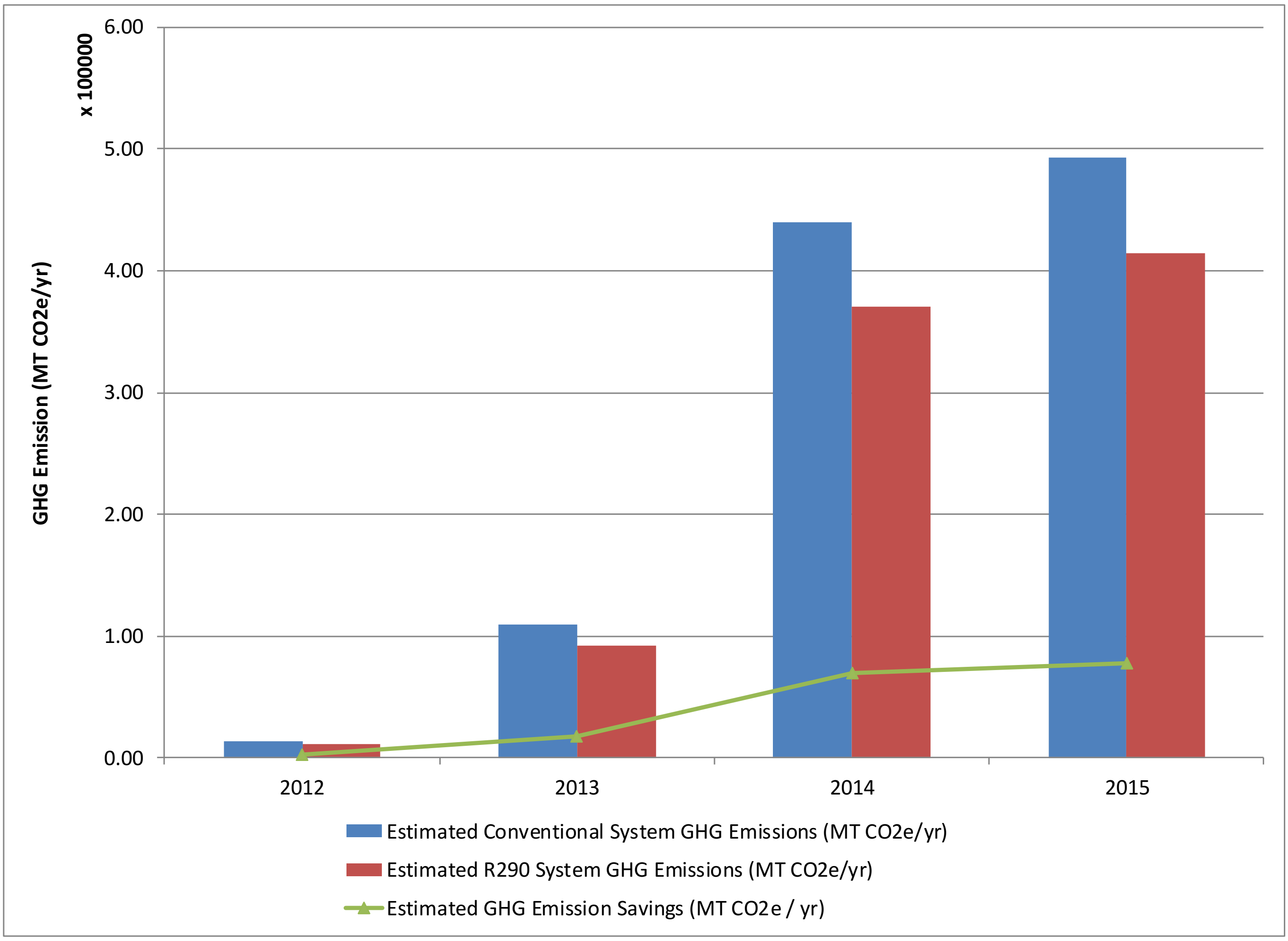
Cumulative GHG emissions from both electricity and refrigerant for these installed units until 2015 accounted for 8,88,907 MT CO_2e, whereas, from equivalent number of TR units from a conventional AC was 15.8% higher at 10,55,898 MT CO_2e. However, it is evident that a major chunk and difference of GHG emission savings came from using R290. In this case, while GHG emissions from conventional refrigerants were 77,987 MT CO2e, R290 based emissions amounted to merely 30 MT CO2e, i.e. 1/2,600th of emissions from conventional refrigerants. Further, from using R290 based ACs, a power and energy saving reduction of 9.1% was observed.

Figure 21 | Energy Consumption: Conventional System vs R290 System



Source: cBalance Solutions Hub analysis

Figure 22 | GHG Emission: Conventional System vs R290 System



Source: cBalance Solutions Hub analysis

2.1.1.3 Growth Projection

Assumptions

- For comparison purposes, conventional AC system is assumed to be a 3-star AC (most widely used AC in India in the residential sector) with a COP of 3.05 as the baseline
- Conventional System Specifications: average refrigerant mix; stand-alone commercial applications; capacity Range of 0.2 TR to 6 TR; average efficiency
- In order to calculate GHG emissions, the type of refrigerant used is R290 with avg. leakage reduction
- Electricity GHG emissions (Includes T&D Losses) 1.19 kg CO2e/kWh
- Scenario 1 - growth projections based on Business-as-usual (BAU)
- Scenario 2 - growth projections based on average growth rate provided by manufacturer(s) (MGR)

In order to project growth for R290 based ACs, two scenarios were modelled. The first scenario took into account the historic data and projected a Business-As-Usual (BAU) growth (*see Figure 23 and Figure* 24). The second scenario projects growth based on statistics provided by the manufacturer(s) or as will be referred to as the Manufacturer Growth Rate (MGR) scenario throughout this study (*see Figure 25 and Figure* 26).

Units & Tonnage

In terms of aggregate TR, under the BAU scenario by 2020, 12,04,294 TR or 9,08,901 (35% 1 TR and 65% 1.5 TR) units of R290 systems would be installed, eight times that of 2015 levels. While under the MGR scenario, 14,73,600 TR or 11,12,151 (35% 1 TR and 65% 1.5 TR) units of R290 systems would be installed, 10 times that of 2015 levels.

Power & Energy Savings

Until 2020, under the BAU scenario, power consumption of conventional AC units was observed at 9,20,092 kW, while that of R290 based AC units was 8,36,323 kW, 9.1% less than conventional AC units. Similarly, under the MGR scenario, power consumption of R290 AC units was less by 74,583 kW (9.1% less). With respect to energy consumption until 2020, under the BAU scenario, energy consumption of conventional AC systems was calculated to be 18,28,437 MWh/yr, while that of R290 AC units was 16,61,967 MWh/yr, with a savings of 1,66,470 MWh/yr. Similarly, even under the MGR scenario, energy worth 1,86,974 MWh/yr was saved (9.1% in both scenarios).

GHG Savings

Under both the scenarios, significant GHG emission savings were estimated as seen in *Figure 24 and Figure* 26. From using R290 based AC units, BAU scenario observed a GHG savings of 3,72,447 MT CO_2e/yr and MGR scenario observed a GHG saving of 4,18,322 MT CO_2e/yr.

2.1.2 Manufacturing Capacity

The only manufacturer at present in India, Godrej & Boyce, reported a manufacturing capacity of 1,80,000 units of R290 based ACs per year.

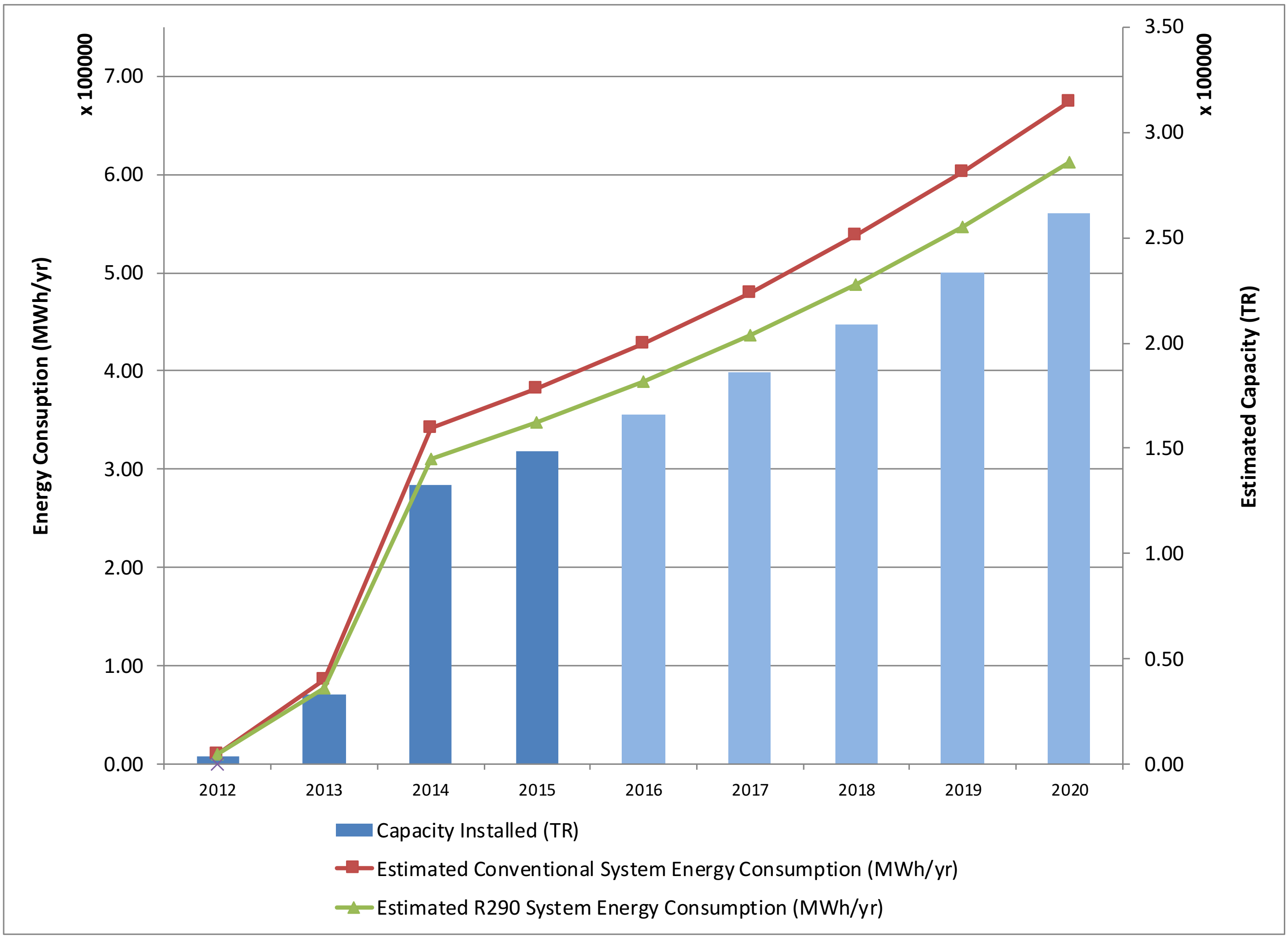
2.1.3 Design Capacity

The R290 based ACs currently available in India are being manufactured for 1 TR & 1.5 TR systems with a refrigerant charge of 350 - 360 gms for 1.5 TR and 310 gms for 1 TR ACs (Colbourne and Usinger, 2015) with and a rated EER of 3.70.

2.1.4 Servicing Capacity

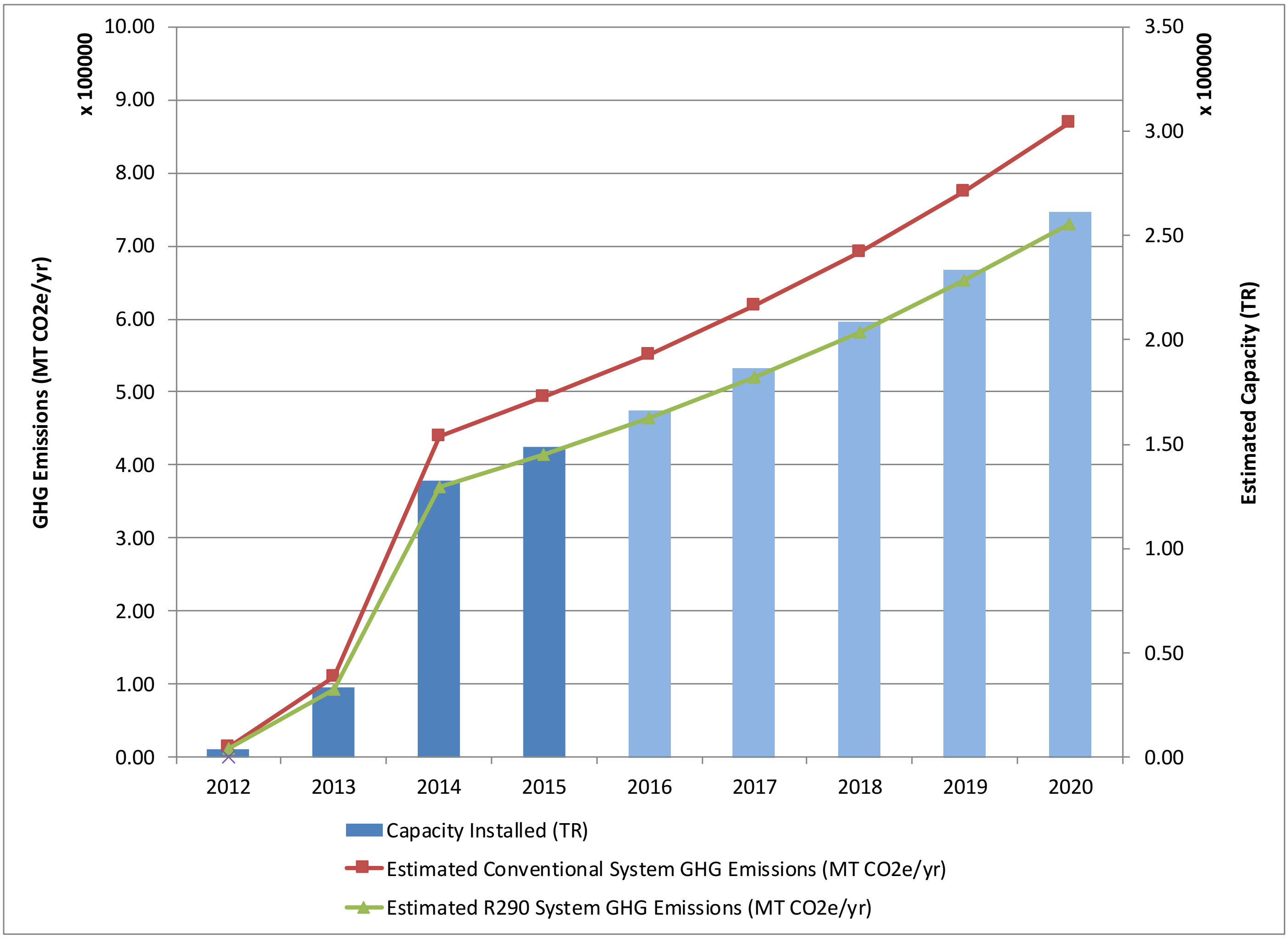
While the exact servicing capacity details are unavailable, however, Godrej & Boyce is the only appliance company in the industry that has been appointed by the Government of India to carry out training for their projects like National CFC Phase-out Plan (NCCoPP) and HIDECOR. Moreover, the vocational training school imparts training across training institutes (ITI's). Godrej has been manufacturing refrigerators with HC refrigerants for over 15 years. Furthermore, more than 10 million units have been installed and are being serviced by Godrej trained field engineers successfully. Additionally, master technicians are trained by a team of Gesellschaft für Internationale Zusammenarbeit (GIZ) GmbH and Godrej experts and only certified technicians are permitted to install/service R290 based ACs. For Split AC units, flaring of connecting pipe ends are not permitted on field and only factory flared connections are used (Godrej, Undated).

Figure 23 | R290 Growth (TR) & Energy Consumption Projection (BAU Scenario)



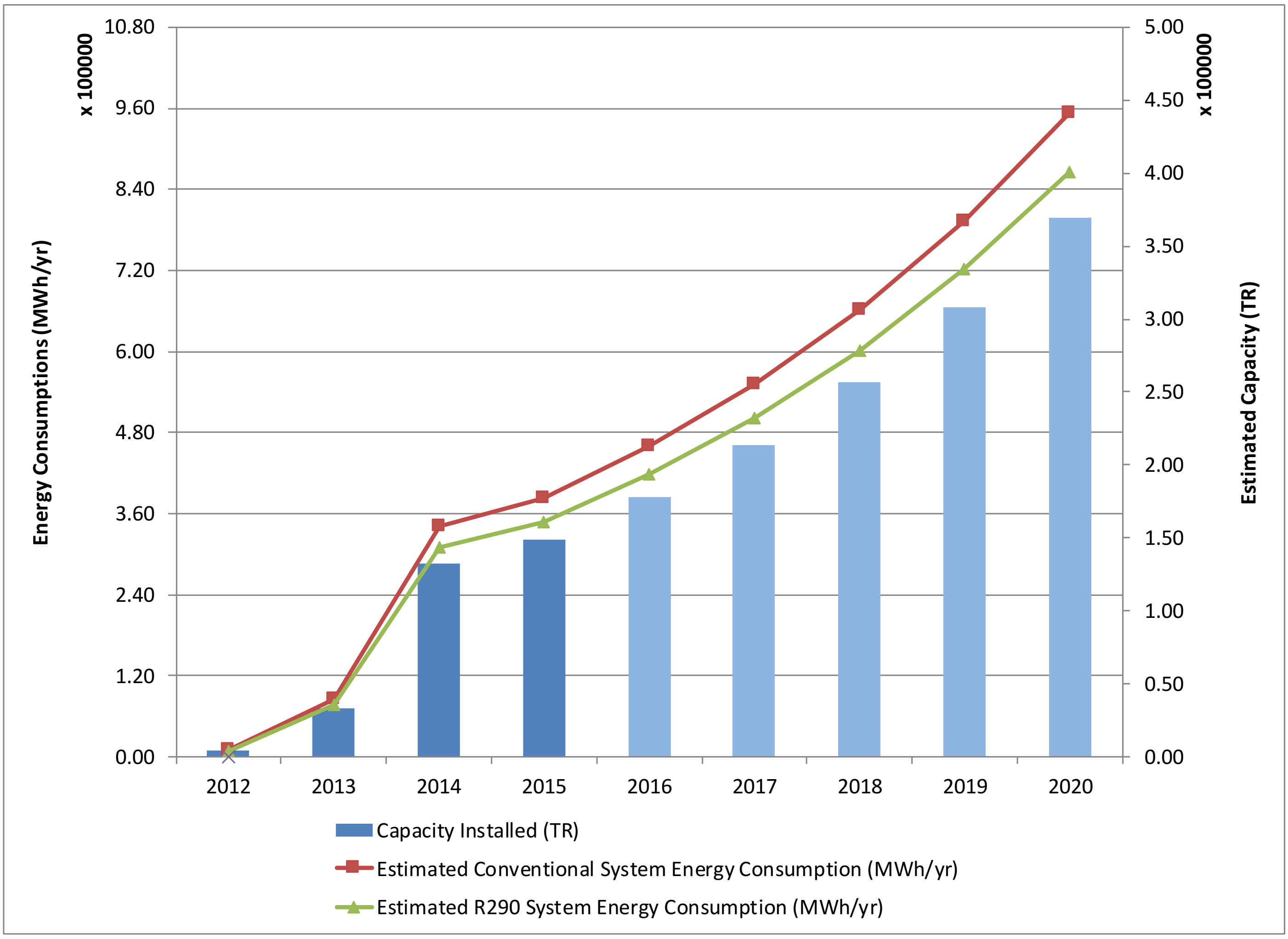
Source: cBalance Solutions Hub analysis

Figure 24 | R290 Growth (TR) & GHG Emission Projection (BAU Scenario)



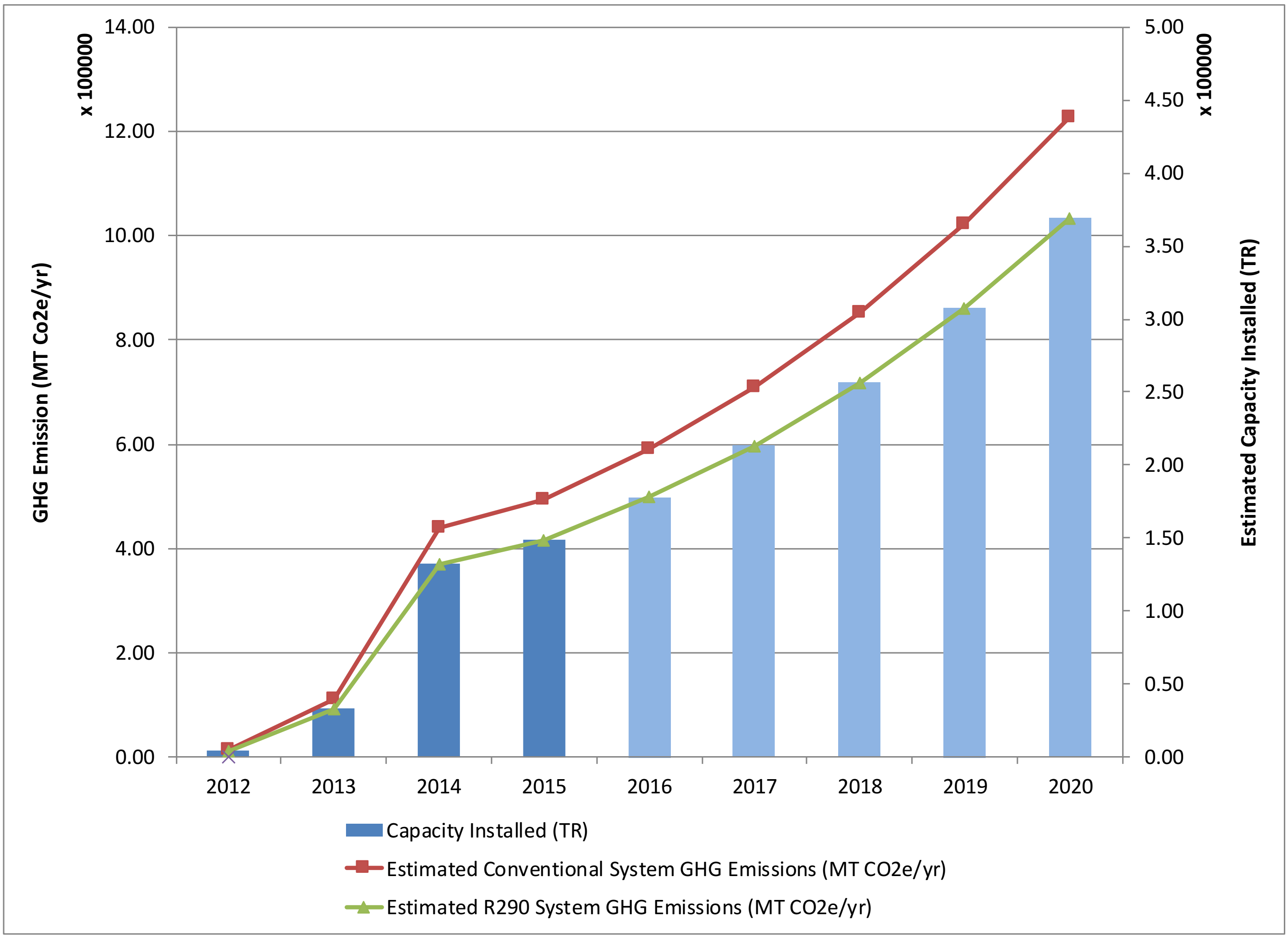
Source: cBalance Solutions Hub analysis

Figure 25 | R290 Growth (TR) & Energy Consumption Projection (MGR Scenario)



Source: cBalance Solutions Hub analysis

Figure 26 | R290 Growth (TR) & GHG Emission Projection (MGR Scenario)

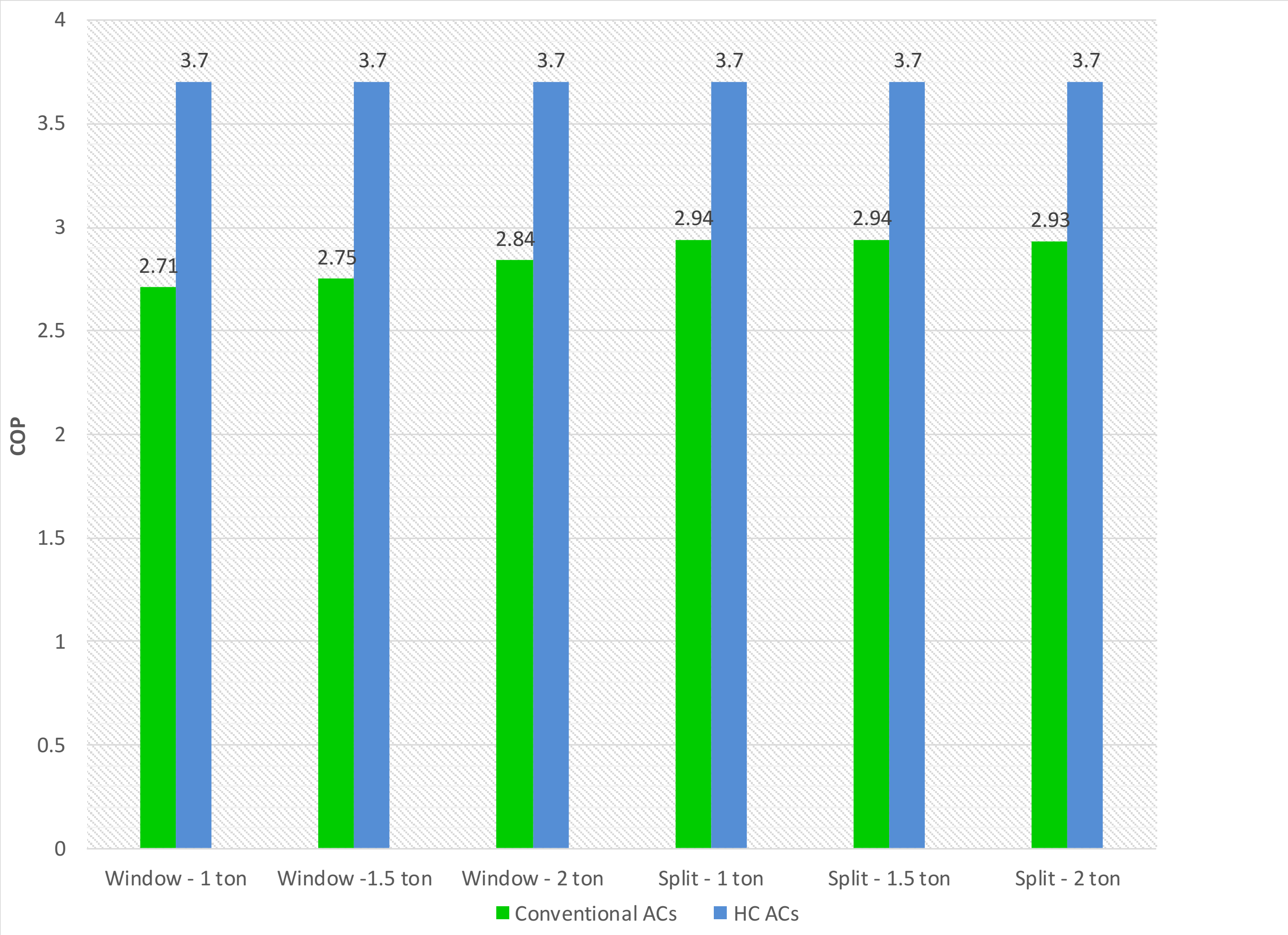


Source: cBalance Solutions Hub analysis

2.1.5 Case Study

In 2012, Godrej & Boyce Inaugurated a new production line for the manufacturing of split and window type propane (R290) air conditioners. The new line is in the 1 & 1.5 TR split AC category, the most common air conditioner capacity segment in India. Moreover, the R290 models consume 21.2% less energy than the current top of line 5 star models across other brands (Godrej, Undated). In comparison to conventional 1 ton and 1.5 ton ACs the R290 ACs reflected a GHG saving percentage of 99.97% and an energy saving of 585 kWh/year/Unit for the 1 TR model and 877 kWh/year/Unit for the 1.5 TR model. Payback period of 3.8 years and 1.8 years was calculated for the 1 TR and 1.5 TR R290 ACs respectively. Lastly, even in the Energy Efficiency Ratio (EER) department, the R290 fares much better than the conventional refrigerant based ACs. The R290 has an EER of 3.7 of cooling/kW power for both 1 TR and 1.5 TR AC, while the conventional split ACs has an EER of 2.94 for both (*See Figure 27*).

Figure 27 | COP comparison of conventional ACs vs HC ACs



Source: cBalance Solutions Hub analysis

A comparative study carried out by Godrej & Boyce between R290 and R22 based ACs reveals that not only is R290 suitable for high ambient regions, variation in COP at high temperatures for HC-290 was the same as that of HCFC-22. Moreover, variation in capacity was also found to be the same and the flammability risk was found to be negligible (*See Table 8 to Table* 9,*Figure 28 to Figure* 30).

Table 8 | Comparison of R22 and R290 ACs – System Characteristics

Sr No	Characteristic	HCFC-22 air conditioner	HC-290 air conditioner
1	Nominal capacity (kW)	5.19	4.83
2	Nominal COP (cooling)	3.08	3.6
3	Evaporator type	Finned Tube	Finned Tube
4	Evaporator block volume (litres)	5.45	5.45
5	Evap no. tubes, circuits	32,3	32,3
6	Evaporator airflow rate (m3/h)	850	850
7	Condenser type	PFC	PFC
8	Condenser block volume (litres)	6.06	6.03
9	Condenser no. tubes	52	52
10	Compressor swept volume (m3/h)	5.27	5.39
11	Compressor rated COP	3.1	3.38
12	Cap tube length (m)	0.8	0.65
13	Cap tube OD (mm),	3	3.2
14	Refrigerant charge (kg)	0.75	0.36

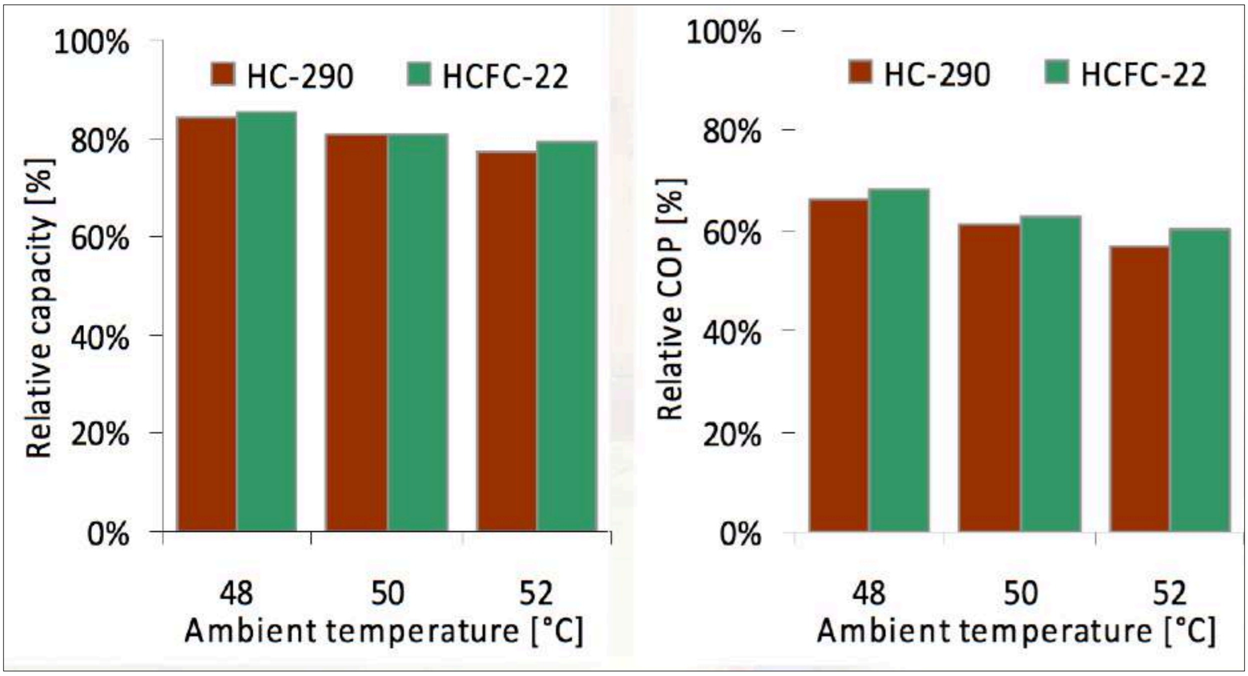
Source: Godrej and Boyce

Table 9 | Comparison of R22 and R290 ACs - Performance Parameters

Parameters	R22	R290
Volumetric Refrigerating Effect (KJ/m^3)	4359	3716
Relative to R22 (%)	0	-15
Discharge Temperature (Deg C)	95	77
Relative to R22 (Deg C)	0	-18
Coefficient of Performance (KW/KW)	4.23	4.28
Relative to R22 (%)	0	1

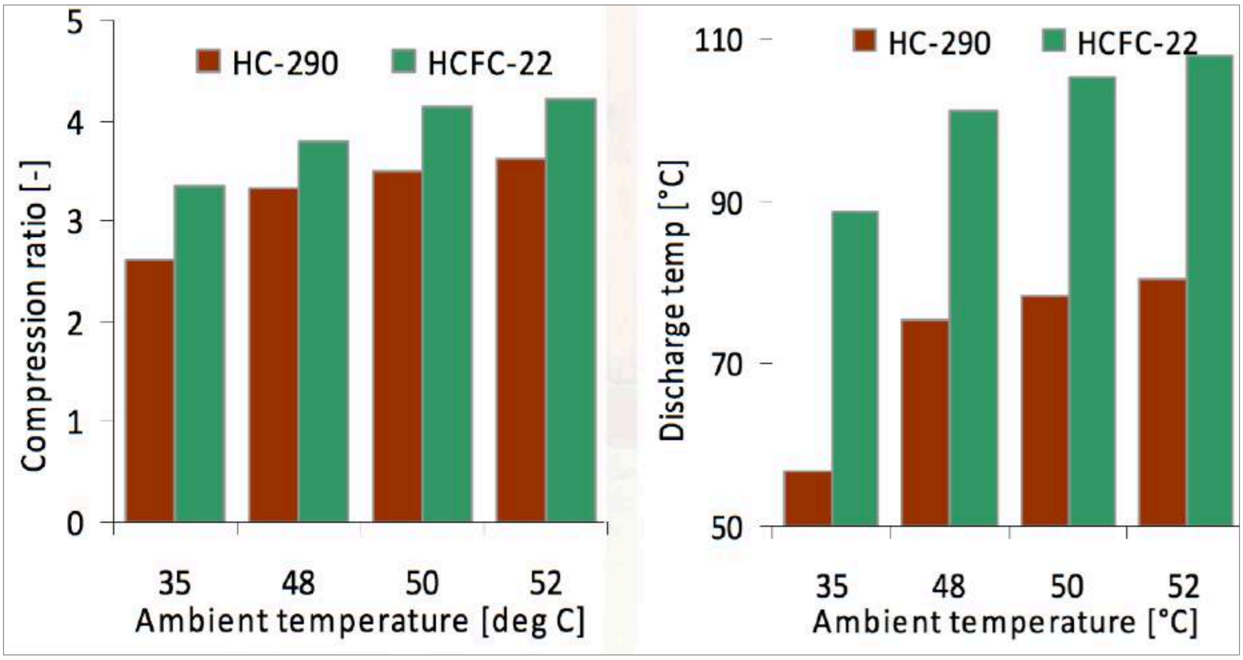
Source: cBalance Solutions Hub analysis

Figure 28 | Comparison of R22 and R290 ACs: I



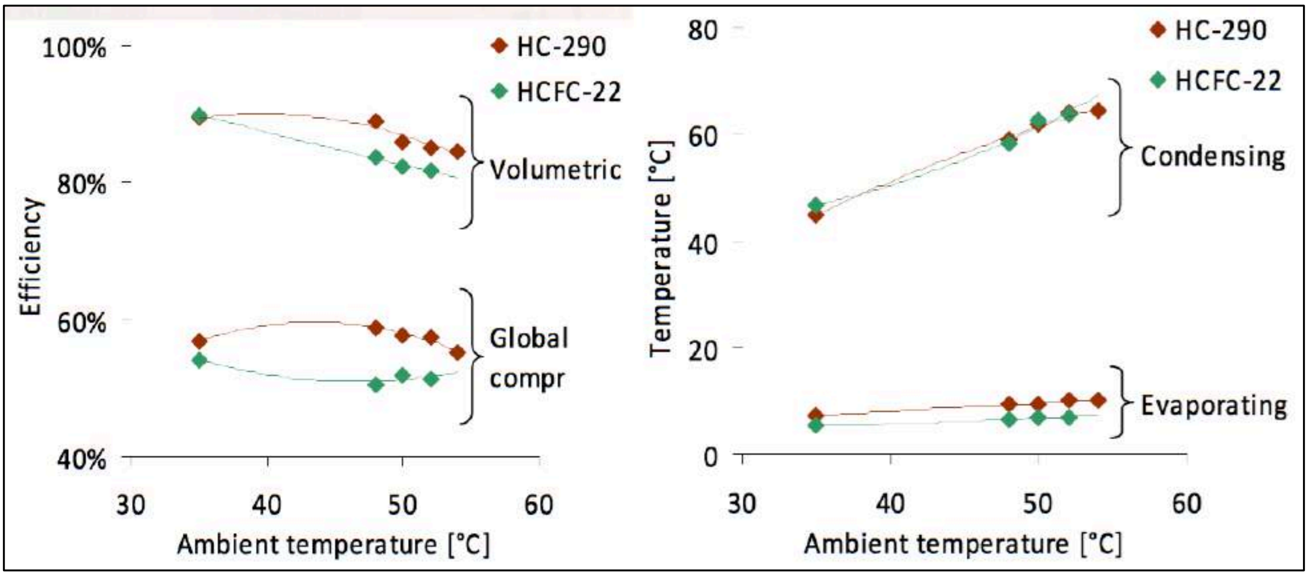
Source: Godrej & Boyce

Figure 29 | Comparison of R22 and R290 ACs: II



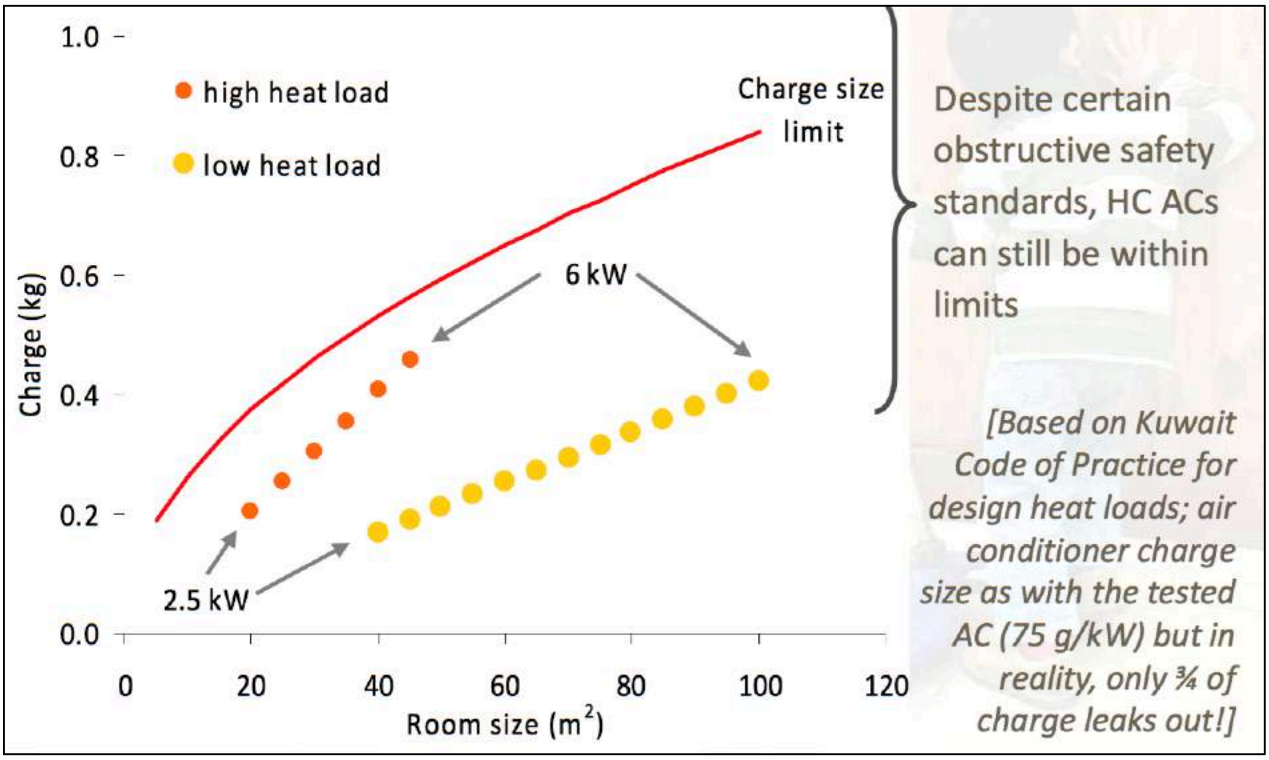
Source: Godrej & Boyce

Figure 30 | Comparison of R22 and R290 ACs: III



Source: Godrej & Boyce

Figure 31 | Charge size limit of R290



Source: Godrej & Boyce

2.2 Vapor Absorption Systems

2.2.1 Current Uptake Scenario

2.2.1.1 Applicable Sectors

Both Ammonia (NH_3) and Lithium Bromide (LiBr) based cooling systems are currently being adopted by the refrigeration sector, both commercial and Industrial.

2.2.1.2 Installed/Sold Capacity

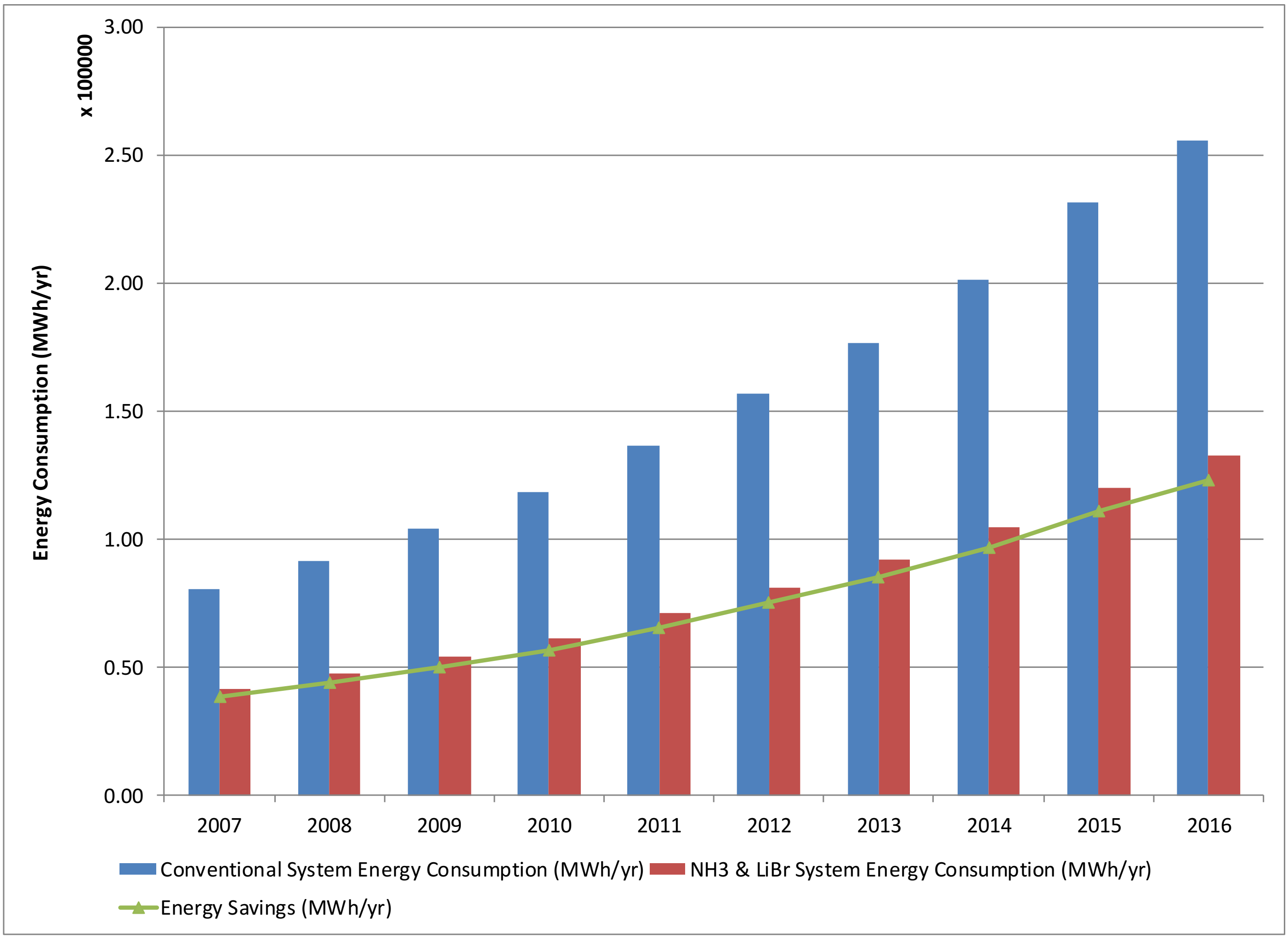
Tonnage

As per data received by five manufacturers of NH_3 and LiBr VAM systems from 2007 till March 2016, an aggregate of 6,02,903 TR has been installed/sold.

GHG, power, & energy consumption and savings

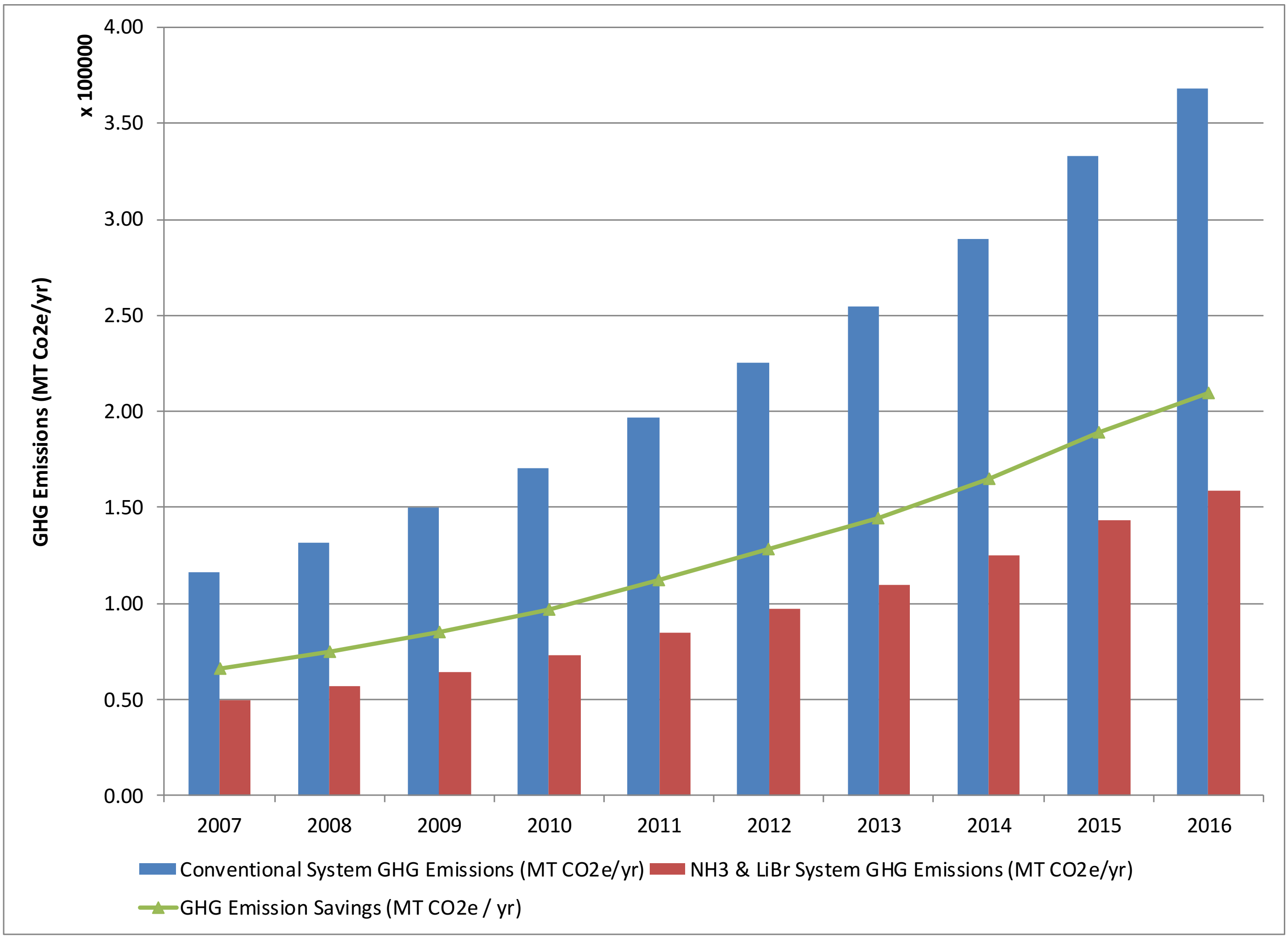
Until March 2016, power consumption from installed NH_3/LiBr systems was estimated to be 3,61,742 kW, while that from conventional systems was 6,96,358 kW, higher by 92.5%. Similar trend line was observed for energy consumption, NH_3/LiBr was estimated at 8,07,408 MWh/yr and conventional systems were estimated at 15,54,272 MWh/yr. A total of 12,71,424 MT CO_2e of GHG emissions were estimated to be avoided through NH_3/LiBr based systems from 2007 to March 2016. Emissions from conventional systems were estimated to be 132% more than from NH_3/LiBr systems, primarily since the GWP and ODP of Ammonia and Lithium Bromide is zero.

Figure 32 | Energy Consumption: Conventional System vs NH3/LiBr System



Source: cBalance Solutions Hub analysis

Figure 33 | GHG Emission: Conventional System vs NH3/LiBr System



Source: cBalance Solutions Hub analysis

2.2.1.3 Growth Projection

Assumptions

- For comparison purposes, conventional AC system is assumed to be a 3-star AC (most widely used AC in the residential sector in India) with a COP of 3.05 as the baseline
- Conventional system specifications: average refrigerant mix.; medium & large commercial refrigeration; capacity range 45 to 1770 TR; avg. efficiency
- Since year wise distribution of sold/installed data from manufacturers was not provided. Historic data was back calculated based on past growth rate details (provided by Thermax)
- Electricity GHG emissions (includes T&D losses) 1.19 kg CO2e/kWh
- NH_3 & LiBr Power Consumption = 0.6 kW/TR; based on details provided by manufacturer(s)
- Scenario 1 - growth projections based on Business-as-usual (BAU)
- Scenario 2 - growth projections based on average growth rate provided by manufacturer(s) (MGR)
- Market share for Thermax across NH_3/LiBr systems is around 80% (as suggested by Thermax)

Similar to the BAU and MGR scenarios mentioned in section 2.1.1.3, NH_3/LiBr growth projections were estimated for this section. As per Thermax, which holds 82% (± 4%) of the market share in India for these systems, estimates a 10% growth over the next few years. The same is used for estimating MGR scenario. BAU projections were done based on a growth rate of 13.7%.

Tonnage

Under the BAU scenario, 11,55,947 TR is estimated to be installed, 13 times more than 2015 levels as seen in *Figure 34.* Since the growth rate under the MGR scenario is less than BAU, 11,09,705 TR is estimated to be installed.

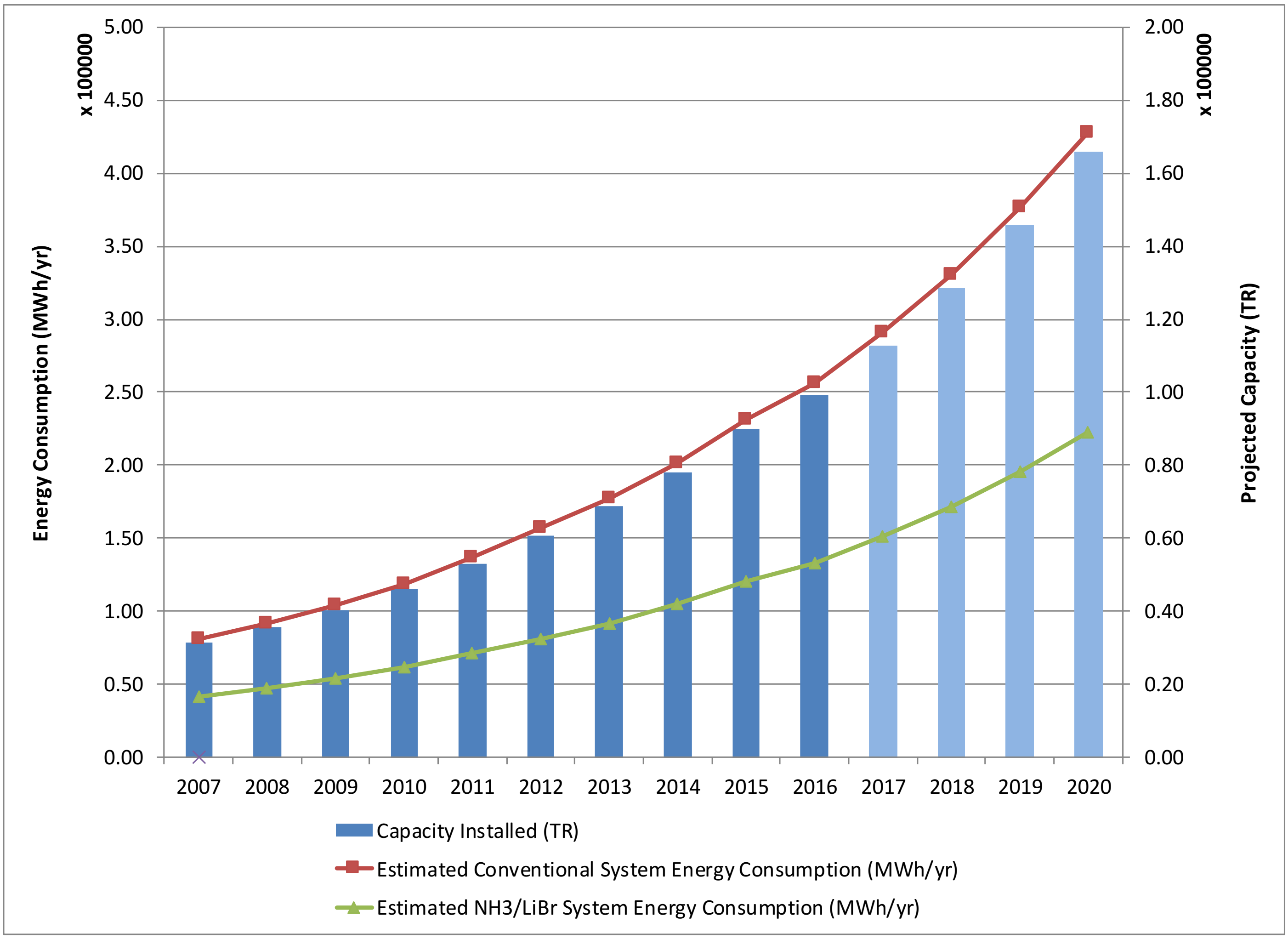
Power and Energy Consumption/Savings

Estimations from both scenarios showcased significant power and energy savings up till 2020. Savings under the BAU scenario till 2020 were estimated at 6,41,560 kW, while under the MGR scenario, a savings of 6,15,896 kW were observed, i.e. a savings of 48.05%. Energy saved till 2020 from use of NH_3/LiBr systems is estimated at 13,74,679 MWh under the MGR scenario, while for the BAU scenario it was 14,31,962 MWh, 48% reduction for both BAU and MGR scenarios.

GHG Emissions

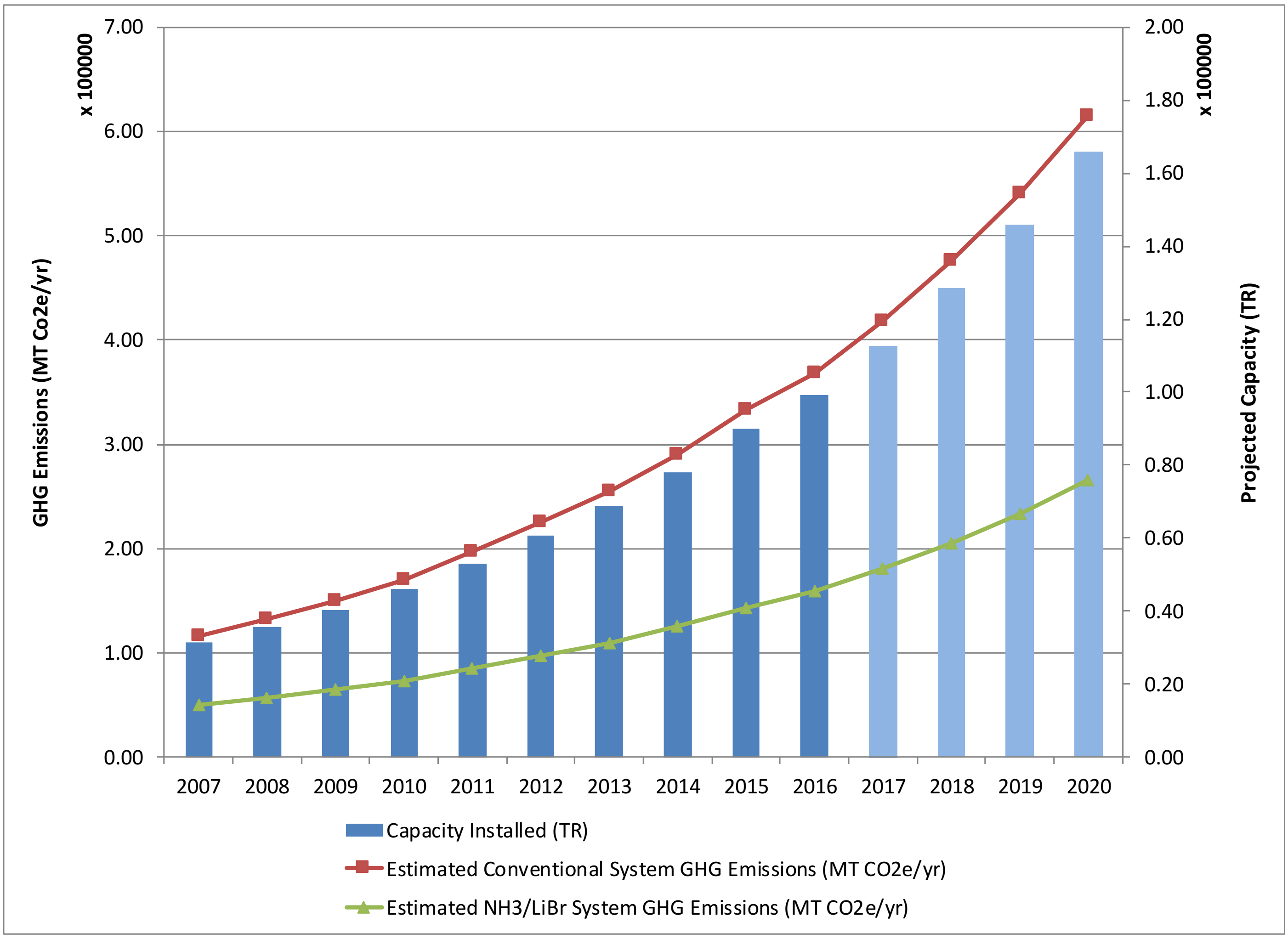
As highlighted in section 2.2.1.2, since GWP and ODP for both NH3 and LiBr are zero, there is a significant reduction in GHG emissions under both BAU and MGR scenarios. By the year 2020, both BAU and MGR scenarios suggest a 56.9% savings in GHG emissions. Under the BAU scenario, while GHG emissions from conventional systems were 42,84,318 MT CO_2e, GHG emissions from NH3/LiBr systems were estimated at 18,46,615 MT CO_2e. In other words, 2.3 times less than emissions from conventional systems. For the MGR scenario, GHG emissions from conventional systems were estimated to be 41,12,931 MT CO_2e and 17,72,744 MT CO_2e from NH_3/LiBr systems. NH_3/LiBr based systems clearly highlight that they fare well under all the three criteria used for growth projections.

Figure 34 | NH3/LiBr VAM Growth (TR) & Energy Consump. Projection (BAU Scenario)



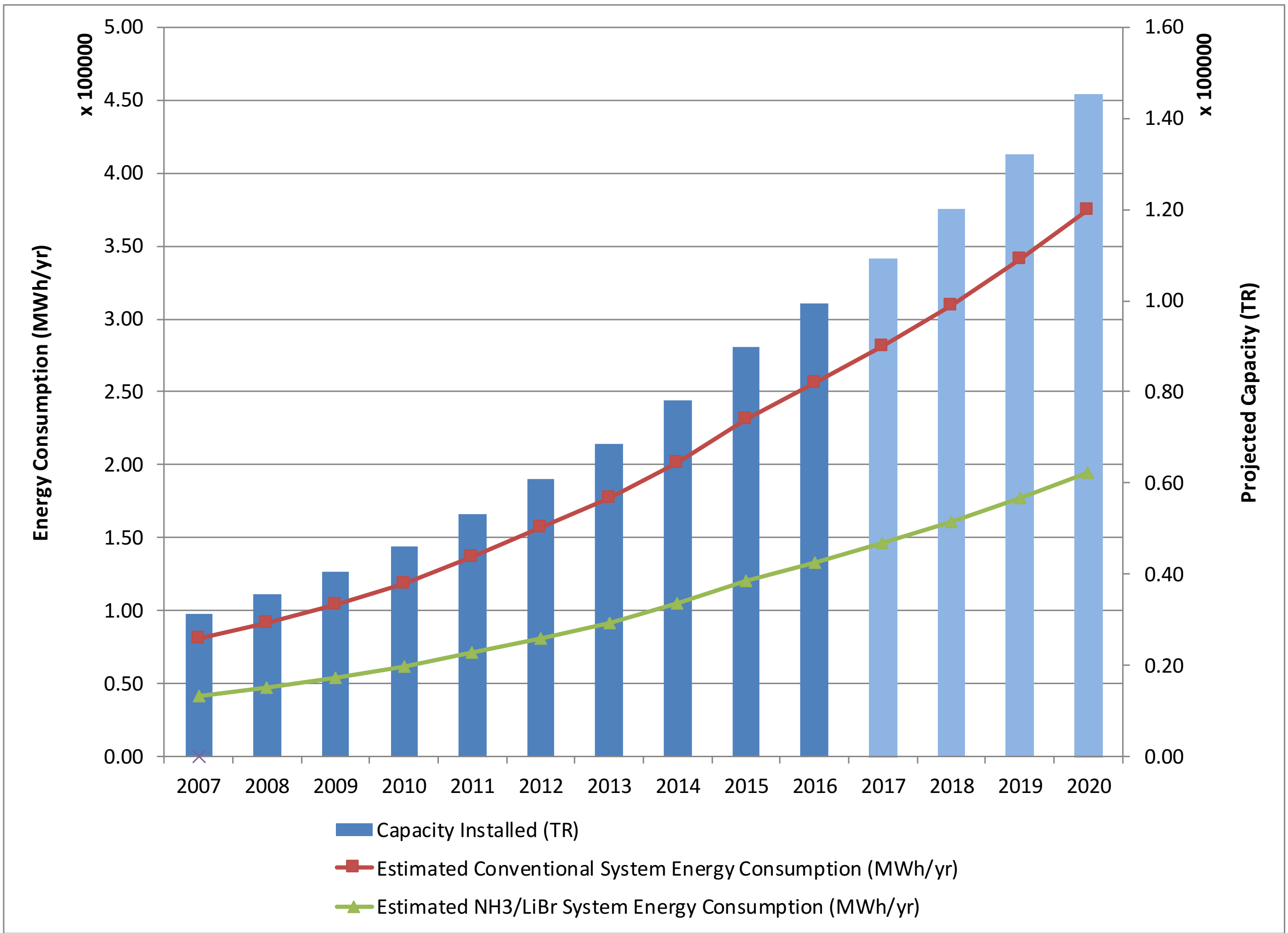
Source: cBalance Solutions Hub analysis

Figure 35 | NH3/LiBr VAM Growth (TR) & GHG Emission Projection (BAU Scenario)



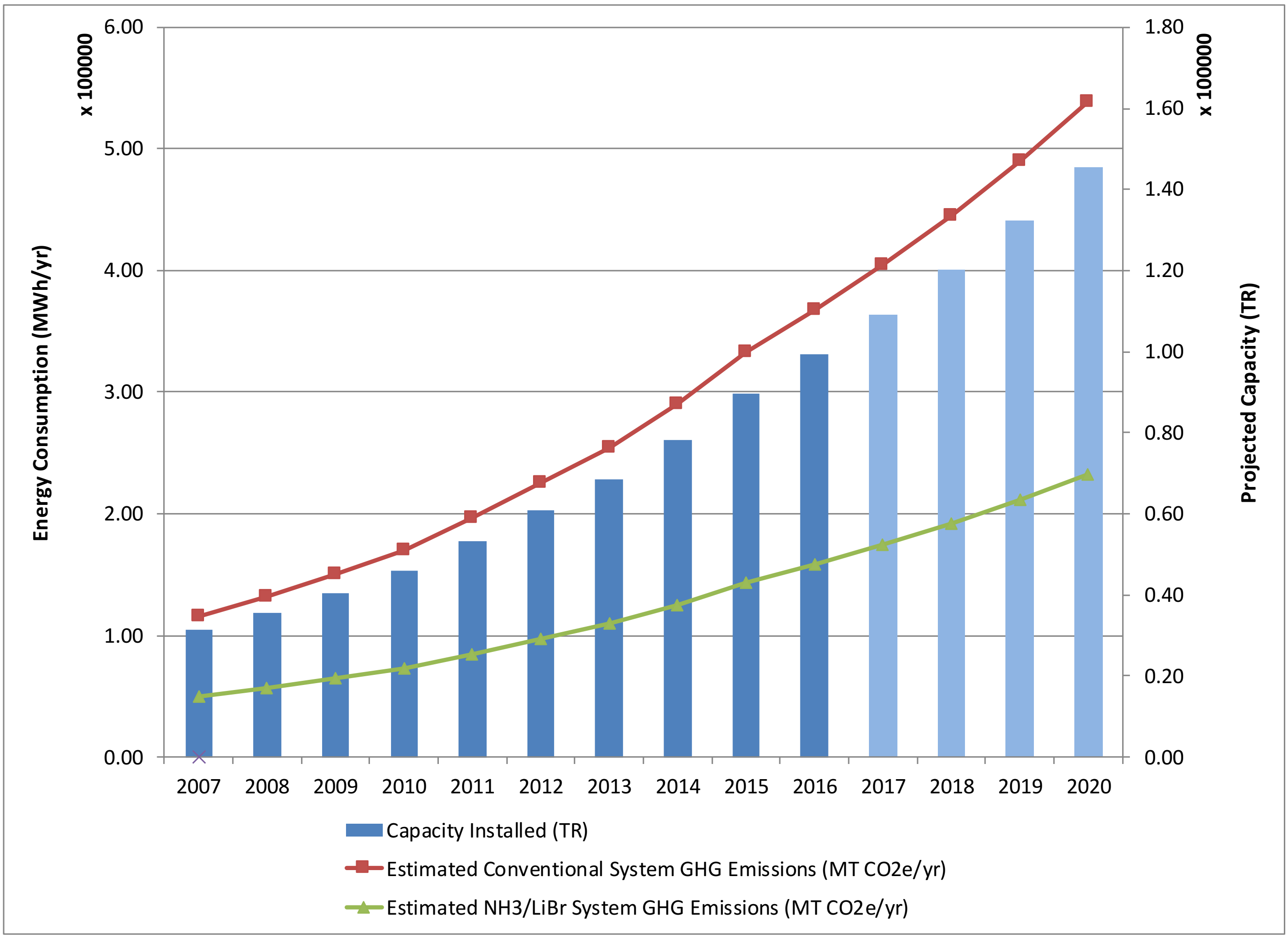
Source: cBalance Solutions Hub analysis

Figure 36 | NH3/LiBr VAM Growth (TR) & Energy Consump. Projection (MGR Scenario)



Source: cBalance Solutions Hub analysis

Figure 37 | NH3/LiBr VAM Growth (TR) & GHG Emission Projection (MGR Scenario)



Source: cBalance Solutions Hub analysis

2.2.2 Manufacturing Capacity

No data available.

2.2.3 Design & Installation Capacity

The design capacity of NH3 & LiBr HVAC based systems range from of as low as 3 TR to a maximum (installed till date in India) of 3,000 TR.

2.2.4 Servicing Capacity

No data available.

2.2.5 Case Studies

2.2.5.1 First Esco – Solar Vapour Absorption Machines (SVAM)

For this study, 10 TR & 75 TR SVAM by First Esco were considered and compared with conventional chiller systems of similar TR loads. For a 10 TR SVAM System, a solar field of approximately 160 Sq. meters is required to install the solar collectors. The resultant savings in energy and emissions would be 36,300 kWh/yr and 44 tons GHG emission/yr. The working principal is similar to that of a conventional Vapour Absorption Machine, however, the only and significant dissimilarity being the heat source of the generator. In the case of a SVAM, the solar collector directly heats the refrigerant through the help of collector tubes and then circulates it to achieve cooling. In other words, solar thermal energy is used to generate chilled water using Vapour Absorption Chillers.

Upon comparison, an energy saving of 84.62% and 43.75% for the 10 TR and 75 TR systems respectively were observed. Additionally, carbon reduced were observed at 44 Tons/yr and 506 Tons/yr as *shown in Table 10 toTable* 11 *and Figure 38 and Figure* 39.

Table 10 | Solar VAM - Specifications of System I under study

Specifications	Unit	Value
Nominal Capacity of Plant	TR	10
Cooling Load	Kcal/hr	30,000
Equivalent Electrical Load	kW	35
Chilled Water Circuit		
Chilled Water Flow Rate	CMH	6
Chilled Water Inlet Temp	Deg C	12
Chilled Water Outlet Temp	Deg C	7
Cooling Water Circuit		
Cooling Water Flow Rate	CMH	8.33
Cooling Water Inlet Temp	Deg C	32
Cooling Water Outlet Temp	Deg C	38
Thermic Fluid Circuit		
Thermic Fluid Flow Rate	CMH	9.33
Thermic Fluid Inlet Temp	Deg C	100
Thermic Fluid Outlet Temp	Deg C	90
Electrical Data		
Power Supply Voltage	V	415
Frequency	Hz	50
Connected Load	kW	15
Solar Field		
Solar Collector Area	Sq. m	80
Roof top/ Ground area for solar field	Sq. m	160
Energy Data -10 TR VCR AC plant		
Connected Load for Conventional AC plant (10 TR)	kW	13

Annual Operating Hours	Hrs/yr	3,300
Energy Consumption-Conventional AC Plant (10 TR)	kWh/yr	42,900
Operating hrs/yr on Solar Radiation	Hrs/yr	3,300
Operating Load with Solar	kW	2
Energy Consumption – Solar Mode	kWh/yr	6,600
Energy savings due to Solar AC Plant	kWh/yr	36,300
Savings Percentage	**%**	**84.62**
Carbon Emissions reduction due to Solar Hybrid Plant	**Tons/yr**	**44**

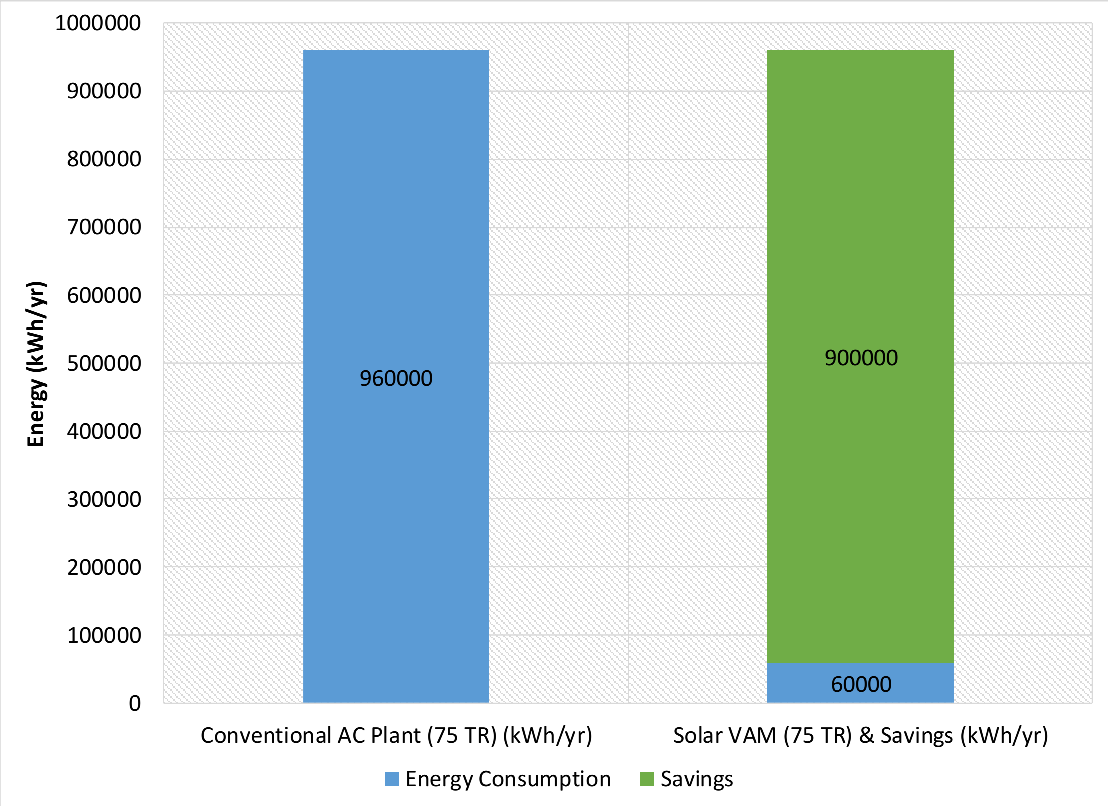
Source: FIRST ESCO India Pvt Ltd

Table 11 | Solar VAM - Specifications of System II under study

Specifications	Unit	Value
Nominal Capacity of Plant	TR	75
Cooling Load	Kcal/hr	2,25,000
Equivalent Electrical Load	kW	262
Chilled Water Circuit		
Chilled Water Flow Rate	CMH	45
Chilled Water Inlet Temp	Deg C	12
Chilled Water Outlet Temp	Deg C	7
Cooling Water Circuit		
Cooling Water Flow Rate	CMH	62.5
Cooling Water Inlet Temp	Deg C	32
Cooling Water Outlet Temp	Deg C	38
Thermic Fluid Circuit		
Thermic Fluid Flow Rate	CMH	70
Thermic Fluid Inlet Temp	Deg C	100
Thermic Fluid Outlet Temp	Deg C	90
Electrical Data		
Power Supply Voltage	V	415
Frequency	Hz	50
Connected Load	kW	15
Solar Field		
Solar Collector Area	Sq. m	1,200
Roof top/ Ground area for solar field	Sq. m	2,400
Energy Data -75 TR VCR AC plant		
Connected Load for Conventional AC plant (75 TR)	kW	120
Annual Operating Hours	Hrs/yr	8,000
Energy Consumption-Conventional AC Plant (75 TR)	kWh/yr	9,60,000
Operating hrs/yr on Solar Radiation	Hrs/yr	4,000
Operating Load with Solar	kW	15
Energy Consumption – Solar Mode	kWh/yr	60,000
Energy savings due to Solar AC Plant	kWh/yr	4,20,000
Savings Percentage	**%**	**43.75**
Carbon Emissions reduction due to Solar Hybrid Plant	**Tons/yr**	**506**

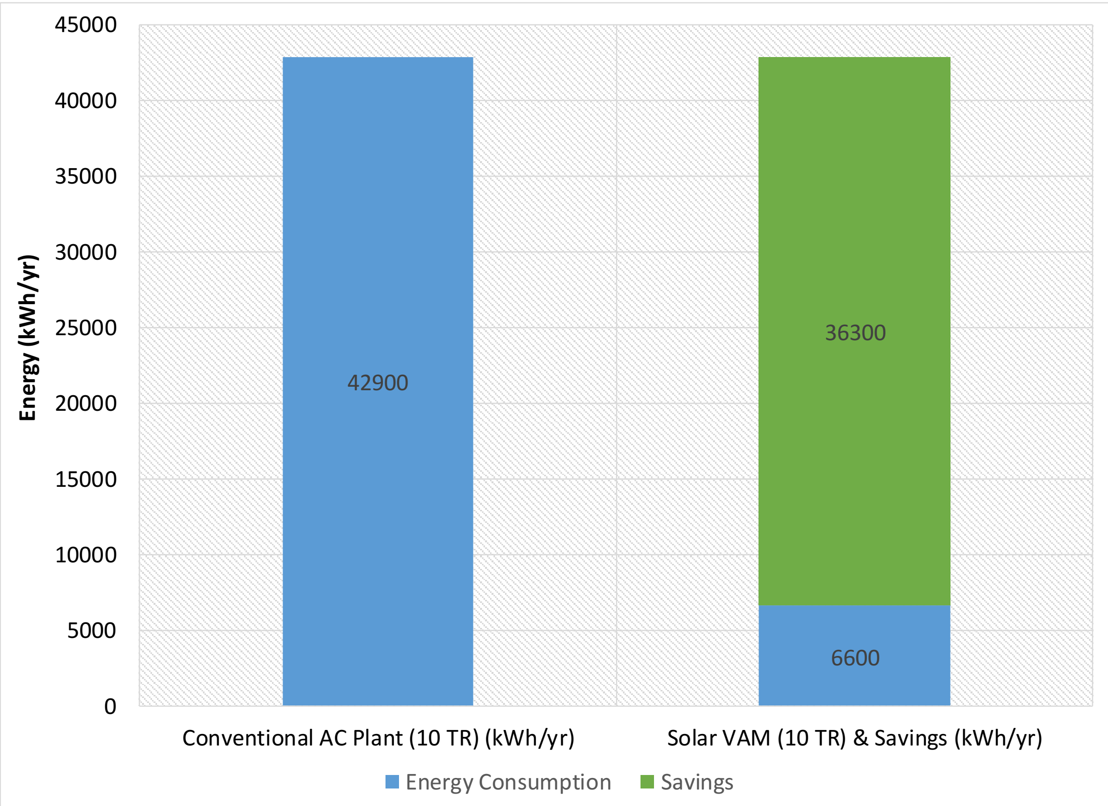
Source: FIRST ESCO India Pvt Ltd

Figure 38 | Energy Consumption and Savings – 75 TR system



Source: cBalance Solutions Hub analysis

Figure 39 | Energy Consumption and Savings – 10 TR System



Source: cBalance Solutions Hub analysis

2.2.5.2 Thermax –VAM

While the GHG and Energy savings have been highlighted in the previous case study, this case focuses on providing the benefits on operational costs and savings. A 100 TR conventional chiller is compared with a 100 TR Thermax VAM chiller. As highlighted in *Table 12*, savings of almost INR 20 Lacs is observed per year. This finding suggests critical monetary benefits adding to the already realised energy savings and GHG emissions reduction.

Table 12 | Case Study analysis for Vapour Absorption Machine

DESCRIPTION	UNIT	Electrical	VAM
Chilling Output	TR	100	100
System type		Reciprocating	Steam fired
Power consumption	KW/hr	150	3
Power cost per unit	Rs/KWH	5	5
Power cost per hour	Rs/hr	675	14
Steam consumption	Kg/hr	NA	461
Steam cost per Kg	Rs/kg	NA	1
Steam cost per hour	Rs/hr	NA	415
Total Operational Cost per hour	Rs/hr	675	428
Operational Savings per hour	Rs/hr	-	247
Operational hours per year	Hrs	-	8,000
Operational Savings per year	**Rs/year**	**-**	**19,72,800**

Source: Thermax

2.3 Structure and Radiant Cooling

2.3.1 Current Uptake Scenario

2.3.1.1 Applicable Sectors

Both Structure and Radiant Cooling systems are used for Stationary Airconditioning (Residential & Commercial) purposes.

2.3.1.2 Installed/Sold Capacity

Structure Cooling

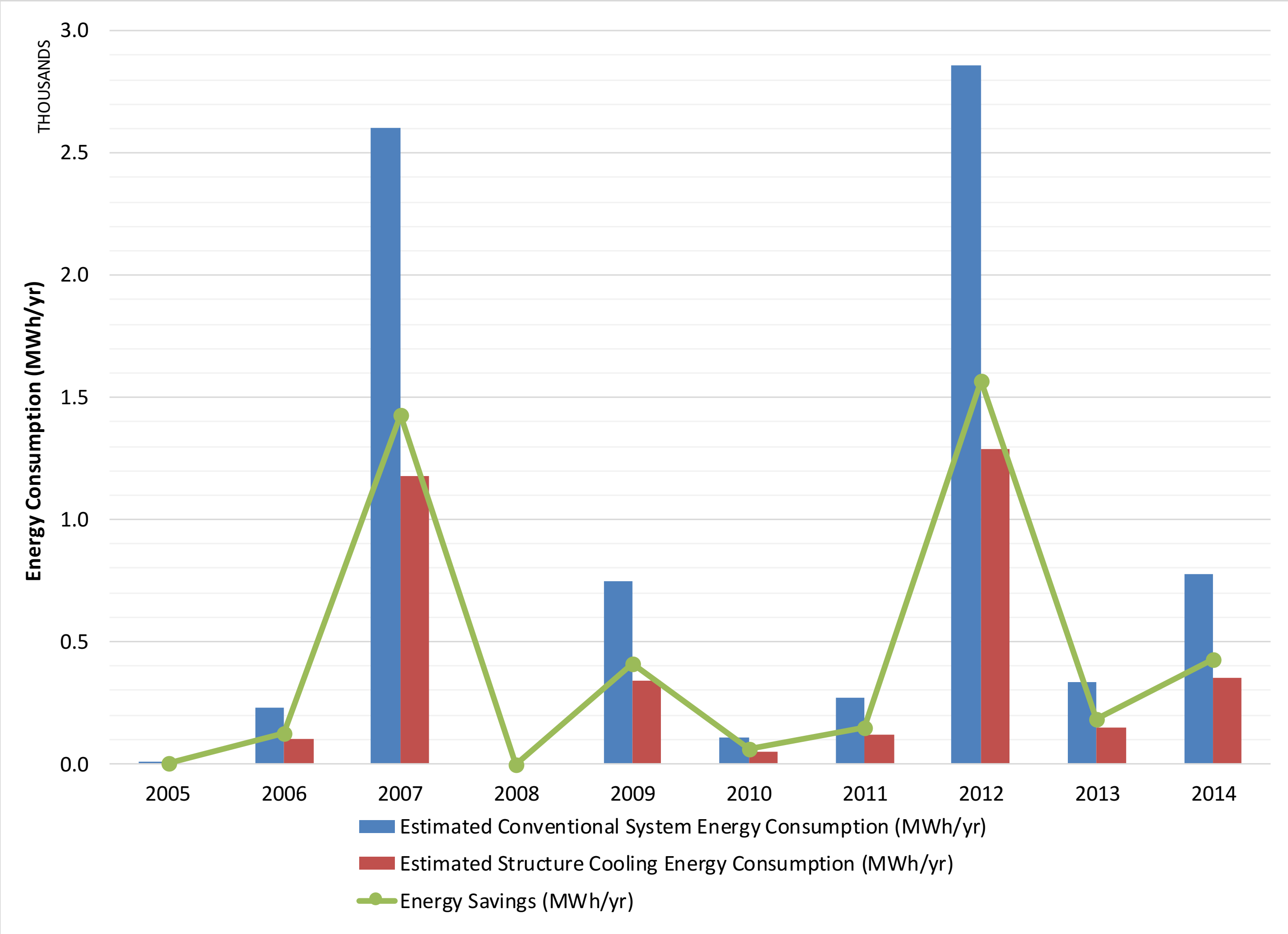
Tonnage

Panasia Engineers are the only manufacturers of Structure cooling system. As per data shareded by Panasia from 2005 till March 2014, an aggregate of 3,65,850 Sq ft has been covered with Structure Cooling system.

GHG, power & energy consumption and savings

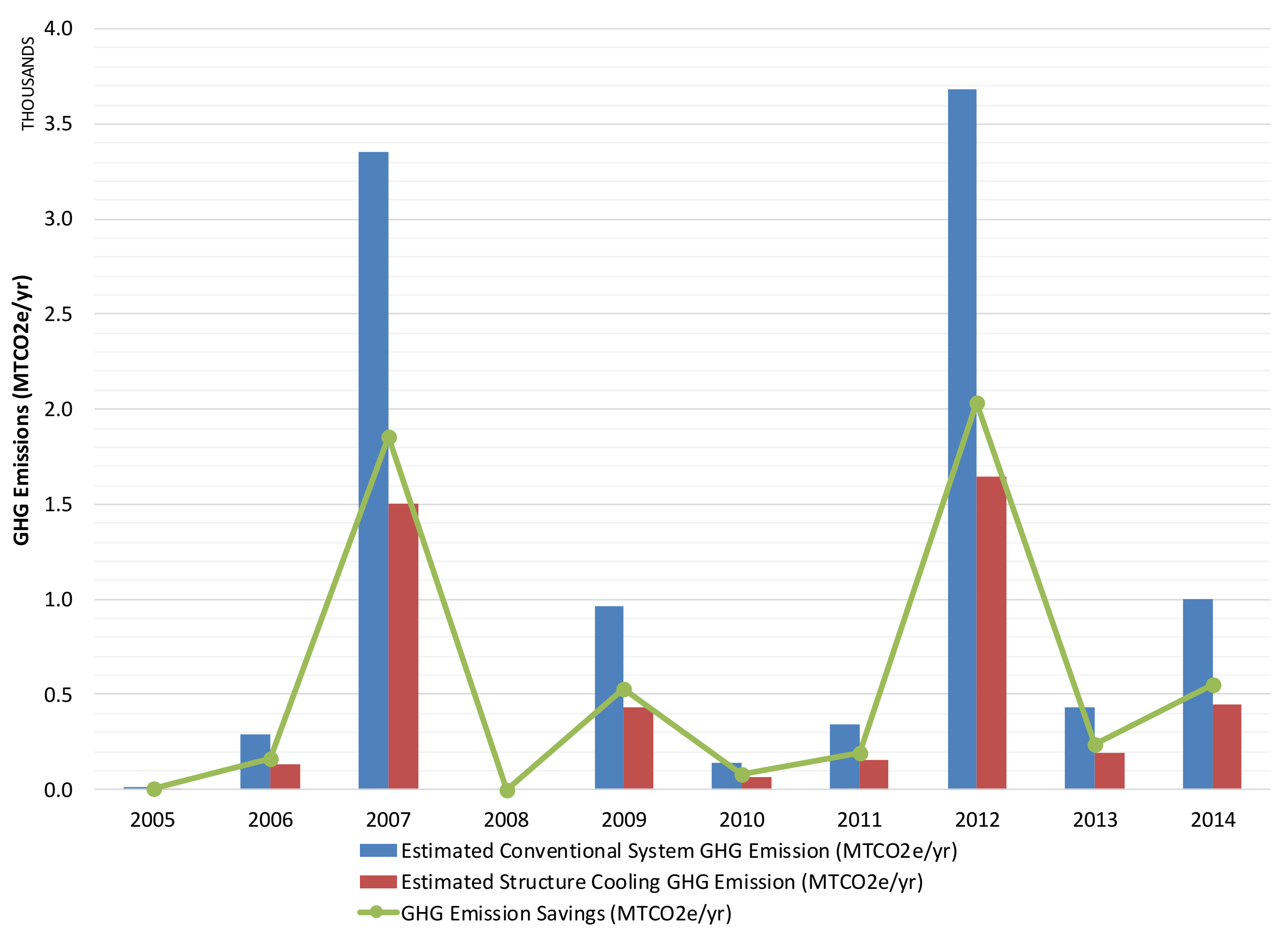
Until March 2014, power consumption from installed Structure cooling systems was estimated to be 1,614 kW, while that from conventional systems was 3,577 kW, higher by 54%. Similar trend line was observed for energy consumption, Structure Cooling was estimated at 3,603 MWh/yr and conventional systems were estimated at 7,985 MWh/yr. A total of 5684 MT CO_2e of GHG emissions were estimated to be avoided through Structure Cooling systems from 2005 to March 2014.

Figure 40 | Energy Consumption: Conventional vs Structure Cooling



Source: cBalance Solutions Hub analysis

Figure 41 | GHG Emission: Conventional vs Structure Cooling



Source: cBalance Solutions Hub analysis

2.3.1.3 Growth Projection

Assumptions

- For comparison purposes, conventional AC system is assumed to be a 3-star AC (most widely used AC in the residential sector in India) with a COP of 3.05 as the baseline
- Conventional system specifications: average refrigerant mix.; medium &large commercial refrigeration; capacity range 45 to 1770 TR; avg. efficiency
- Electricity GHG emissions (includes T&D losses) 1.19 kg CO2e/kWh
- Scenario 1 -growth projections has been done through Linear Equation based on past data.

Tonnage

Under this scenario, 77407 Sq.ft area to be estimated to have structure cooling in 2020. 382 TR is estimated to be installed, 2 times more than 2014 levels as seen in *Figure 43*. Estimated reduction in tonnage is 269 TR.

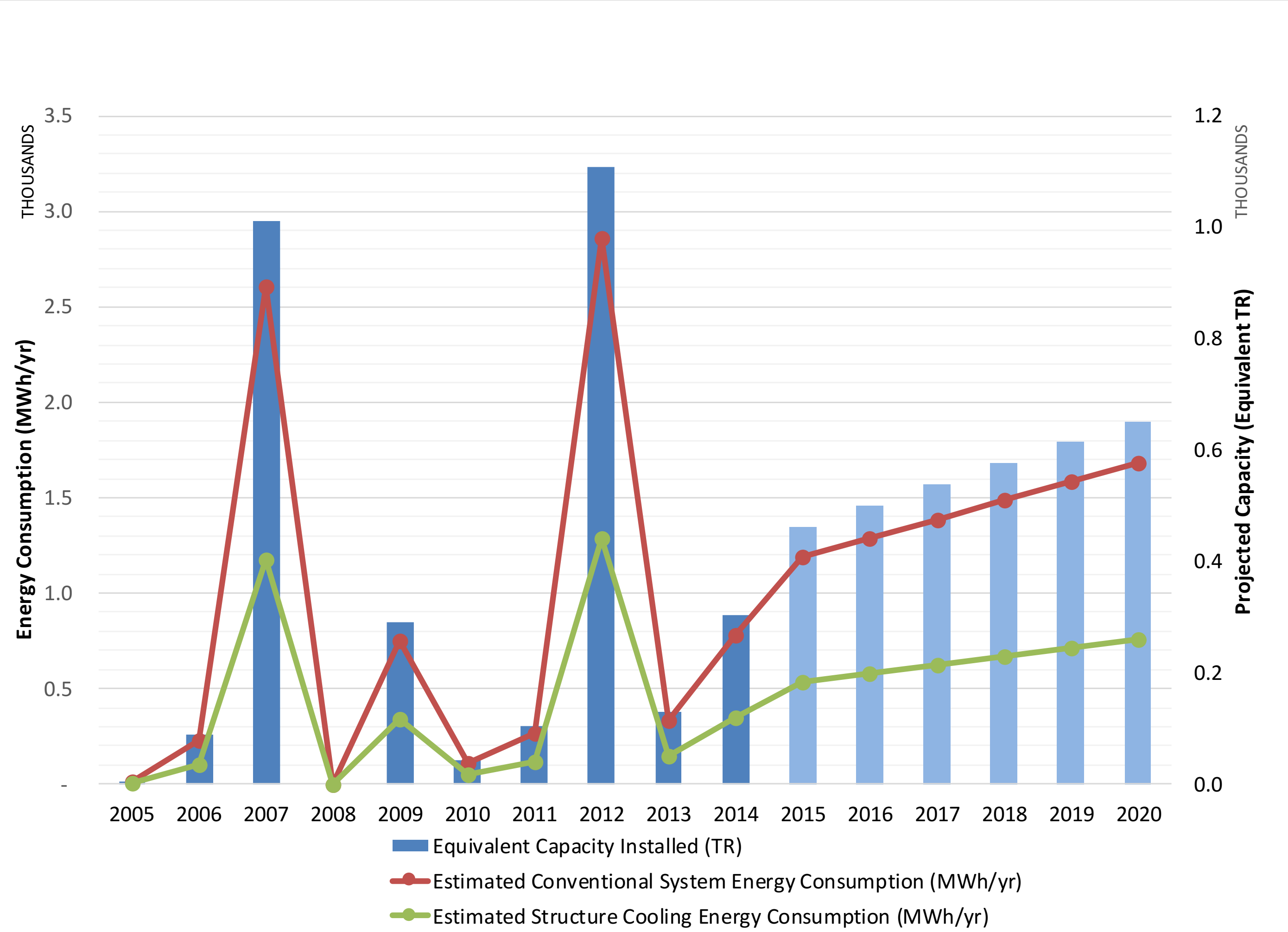
Power and Energy Consumption/Savings

Estimations from scenario showcased significant power and energy savings up till 2020. Savings till 2020 were estimated at 4,082 kW. Energy saved till 2020 from use of Structure Cooling systems is estimated at 9,110 MWh/yr.

GHG Emissions

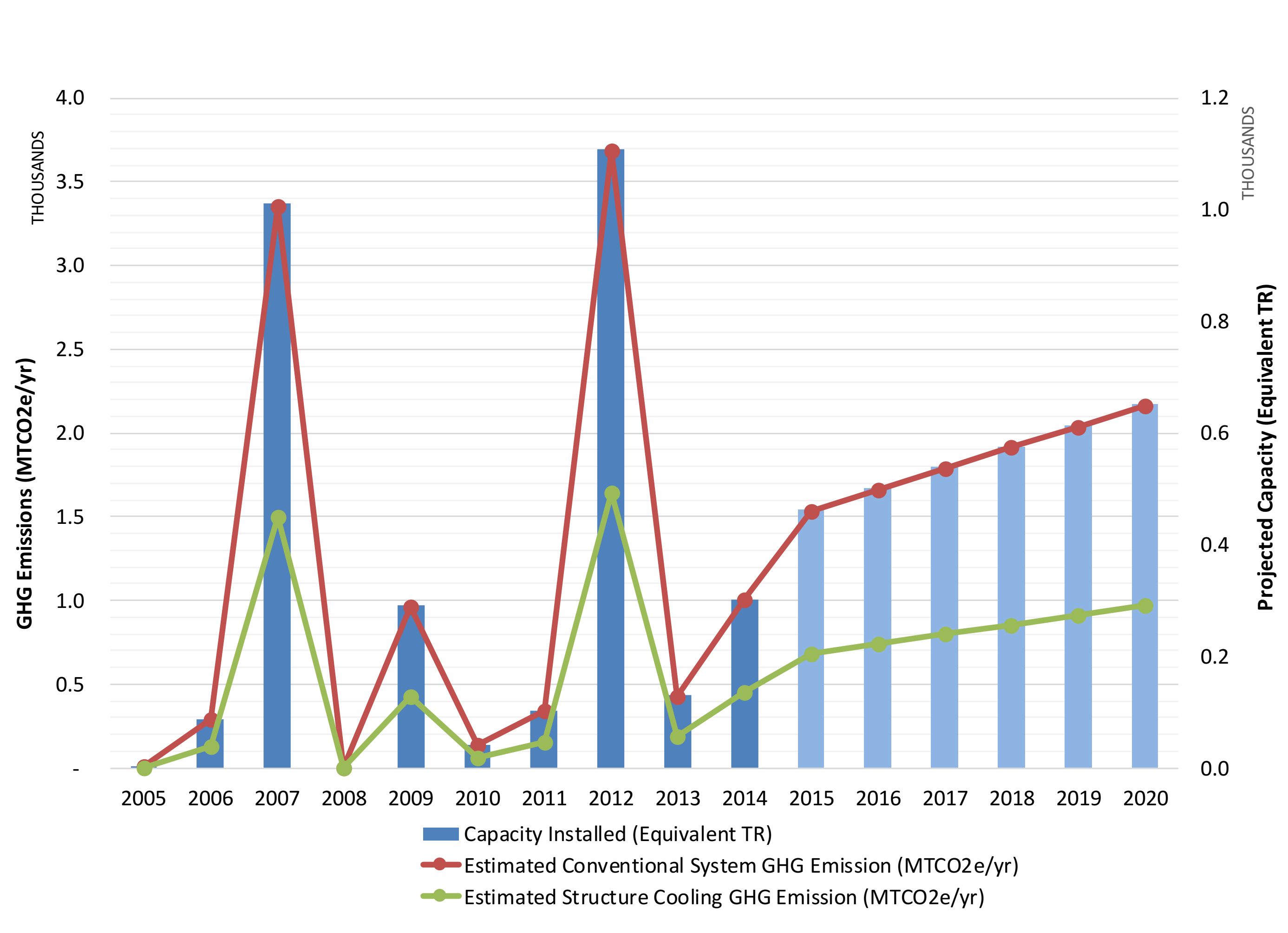
As highlighted in section 2.2.1.2, since GWP and ODP for structure cooling system are zero, there is a significant reduction in GHG emissions under this scenario. By the year 2020, scenario suggest a 55% savings in GHG emissions. While GHG emissions from conventional systems were 21,383 MT CO_2e, GHG emissions from Structure cooling systems were estimated at 9,565 MT CO_2e. In other words, 2.2 times less than emissions from conventional systems.

Figure 42 | Structure Cooling Growth (TR) & Energy Consumption Projection



Source: cBalance Solutions Hub analysis

Figure 43 | Structure Cooling Growth (TR) & GHG Emission Projection



Source: cBalance Solutions Hub analysis

Radiant cooling

2.3.1.4 Installed/Sold Capacity

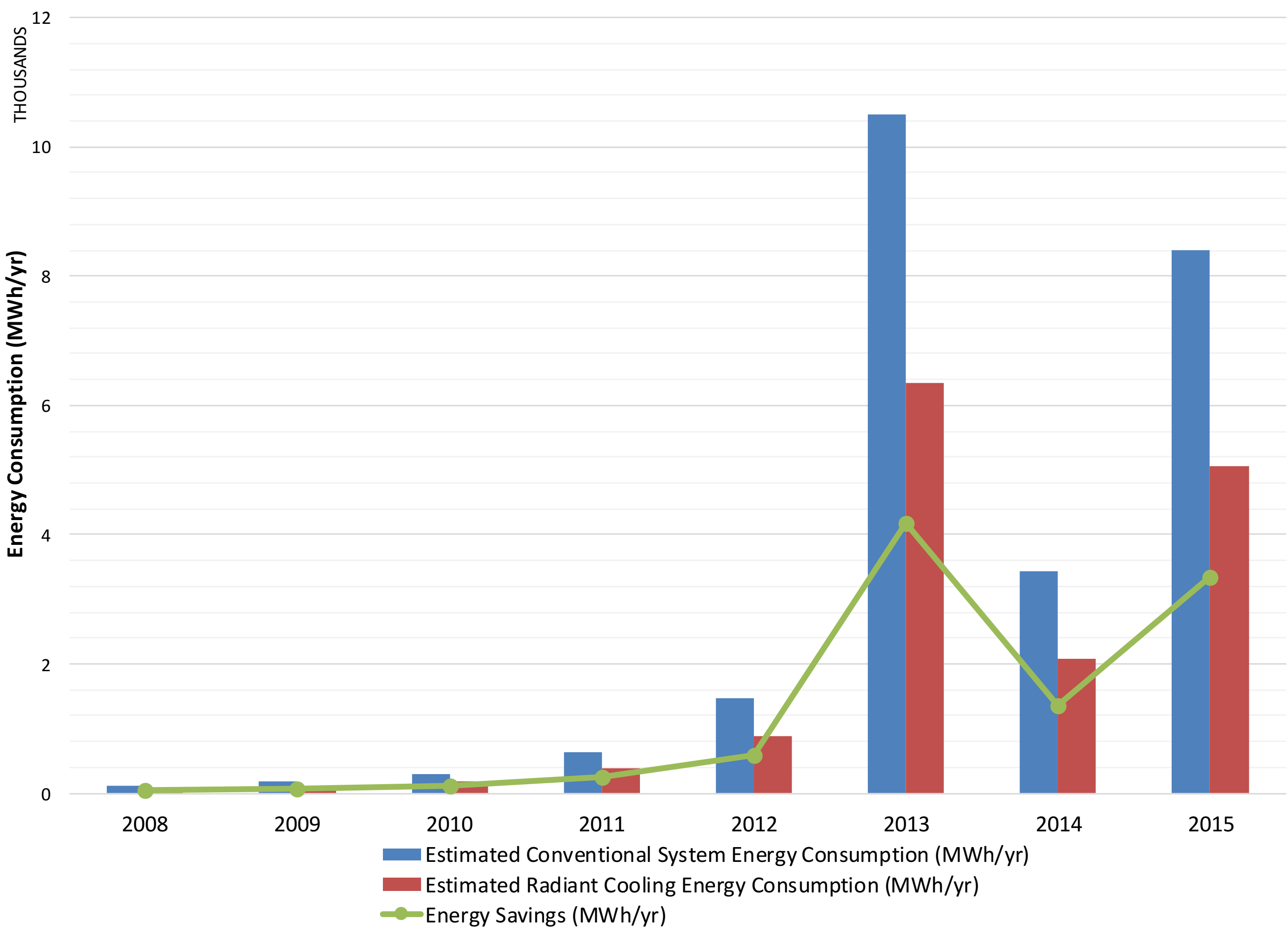
Tonnage

As per data received by four manufacturers of Radiant Cooling systems from 2008 till March 2016, an aggregate of 23,87,087 Sq. ft. has been cooled, which would be approximately equivalent to 10,594 TR worth of conventional system cooling.

GHG, power & energy consumption and savings

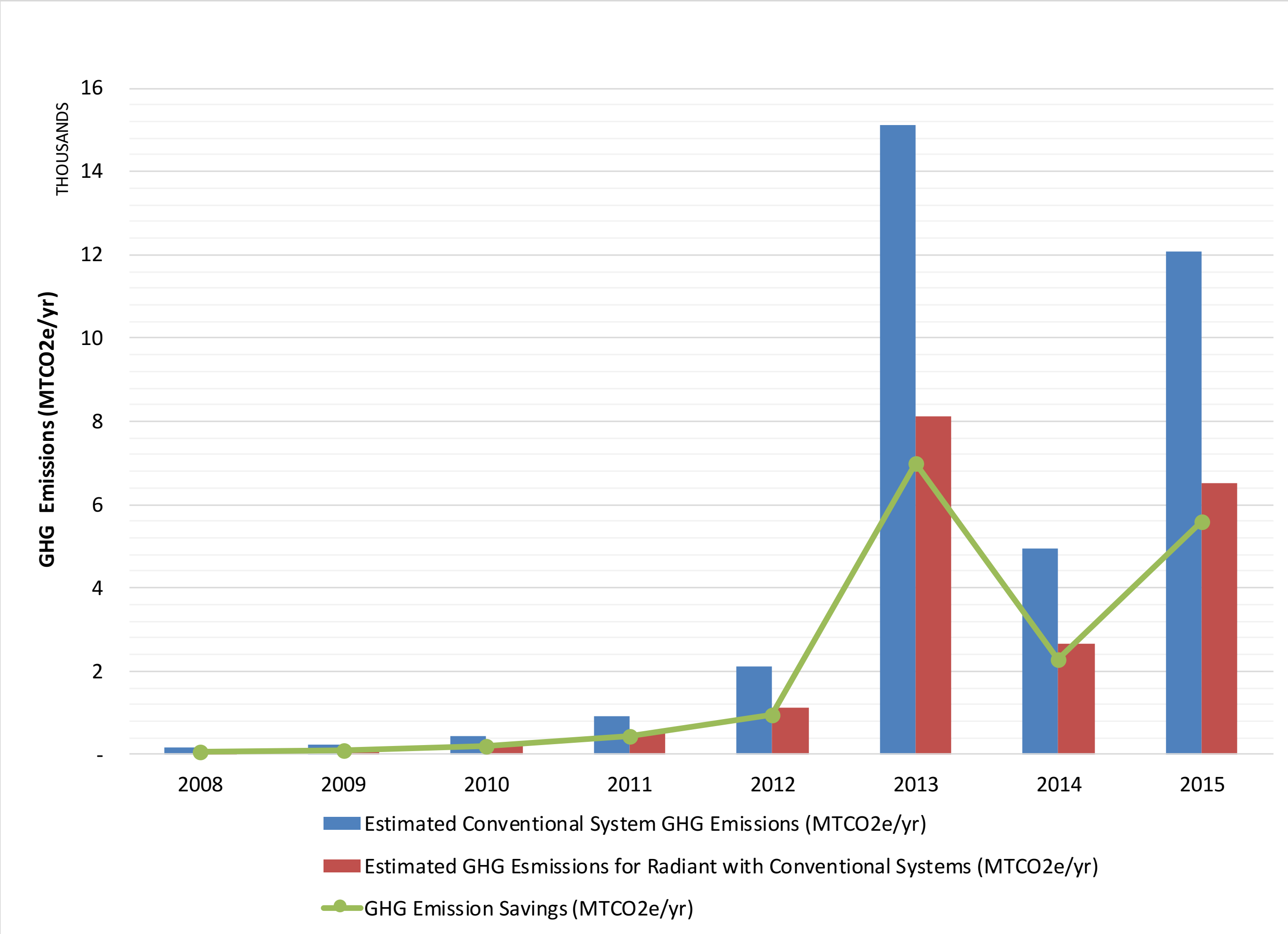
Until March 2016, power consumption from installed Radiant Cooling systems was estimated to be 7,380 kW, while that from conventional systems was 12,236 kW, higher by 65.8%. Similar trend line was observed for energy consumption, Radiant Cooling was estimated at 16,471 MWh/yr and conventional systems were estimated at 27,311 MWh/yr. A total of 18,131 MT CO_2e of GHG emissions were estimated to be avoided through Radiant Cooling systems from 2008 to March 2016.

Figure 44 | Energy Consumption: Conventional System vs Radiant Cooling



Source: cBalance Solutions Hub analysis

Figure 45 | GHG Emission: Conventional System vs Radiant Cooling



Source: cBalance Solutions Hub analysis

2.3.1.5 Growth Projection

Assumptions

- For comparison purposes, conventional AC system is assumed to be a 3-star AC (most widely used AC in the residential sector in India) with a COP of 3.05 as the baseline
- Conventional system specifications: average refrigerant mix.; medium &large commercial refrigeration; capacity range 45 to 1770 TR; avg. efficiency
- Electricity GHG emissions (includes T&D losses) 1.19 kg CO2e/kWh
- Conventional HVAC System Requirements with Radiant Cooling = 30.2 Sq. m/TR
- Scenario 1 -growth projections has been done through polynomial Equation based on past data.

Tonnage

Under this scenario, 53,05,476 Sq. ft. is estimated to be cooled in the next 5 years using Radiant Cooling, which is equivalent to 23,546 TR of conventional cooling.

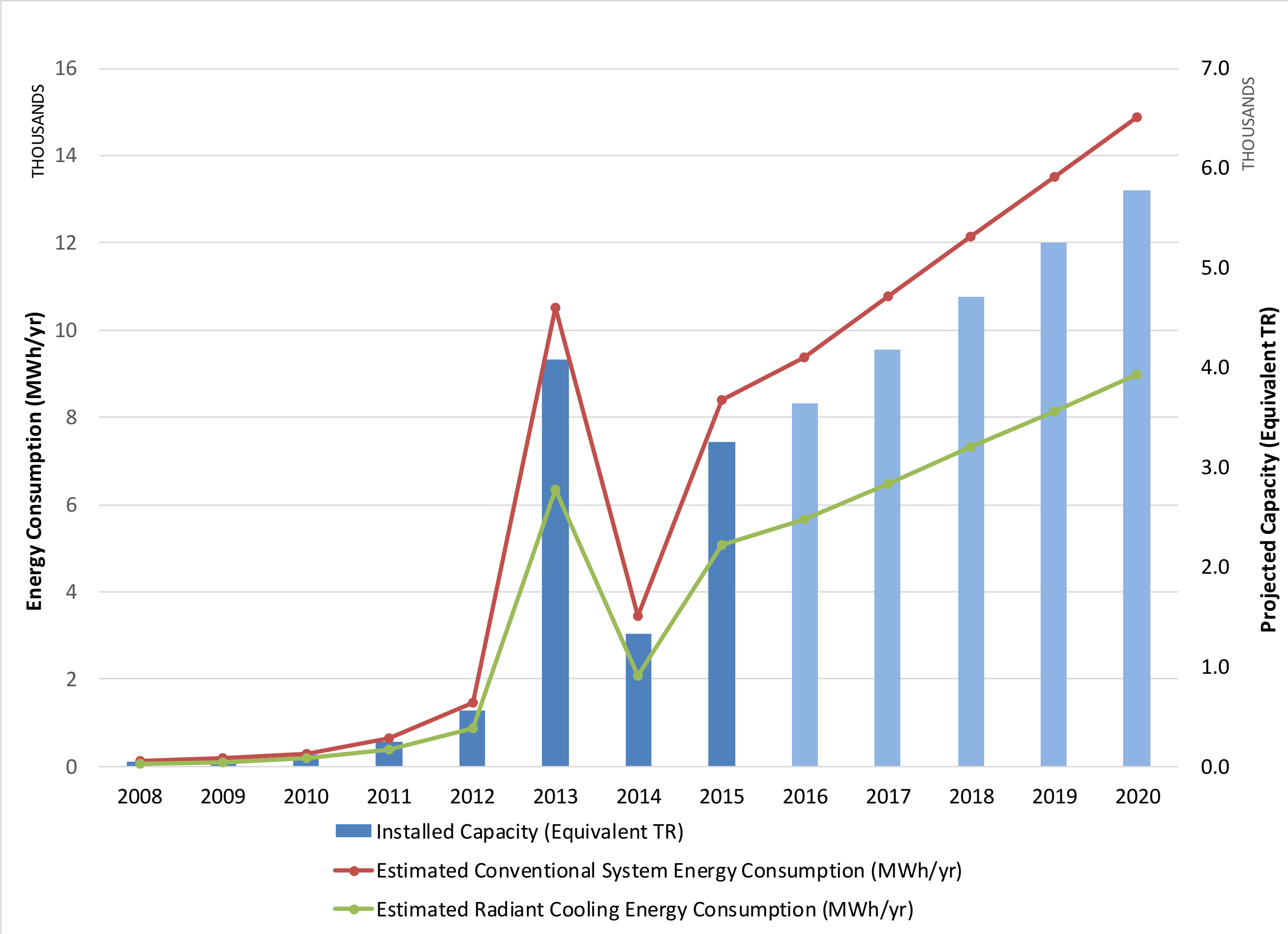
Power and Energy Consumption/Savings

Estimations from scenario showcased significant power and energy savings up till 2020. Savings till 2020 were estimated to be 10,794 kW. Energy saved till 2020 from use of IDEC systems is estimated to be 24,093 MWh/yr.

GHG Emissions

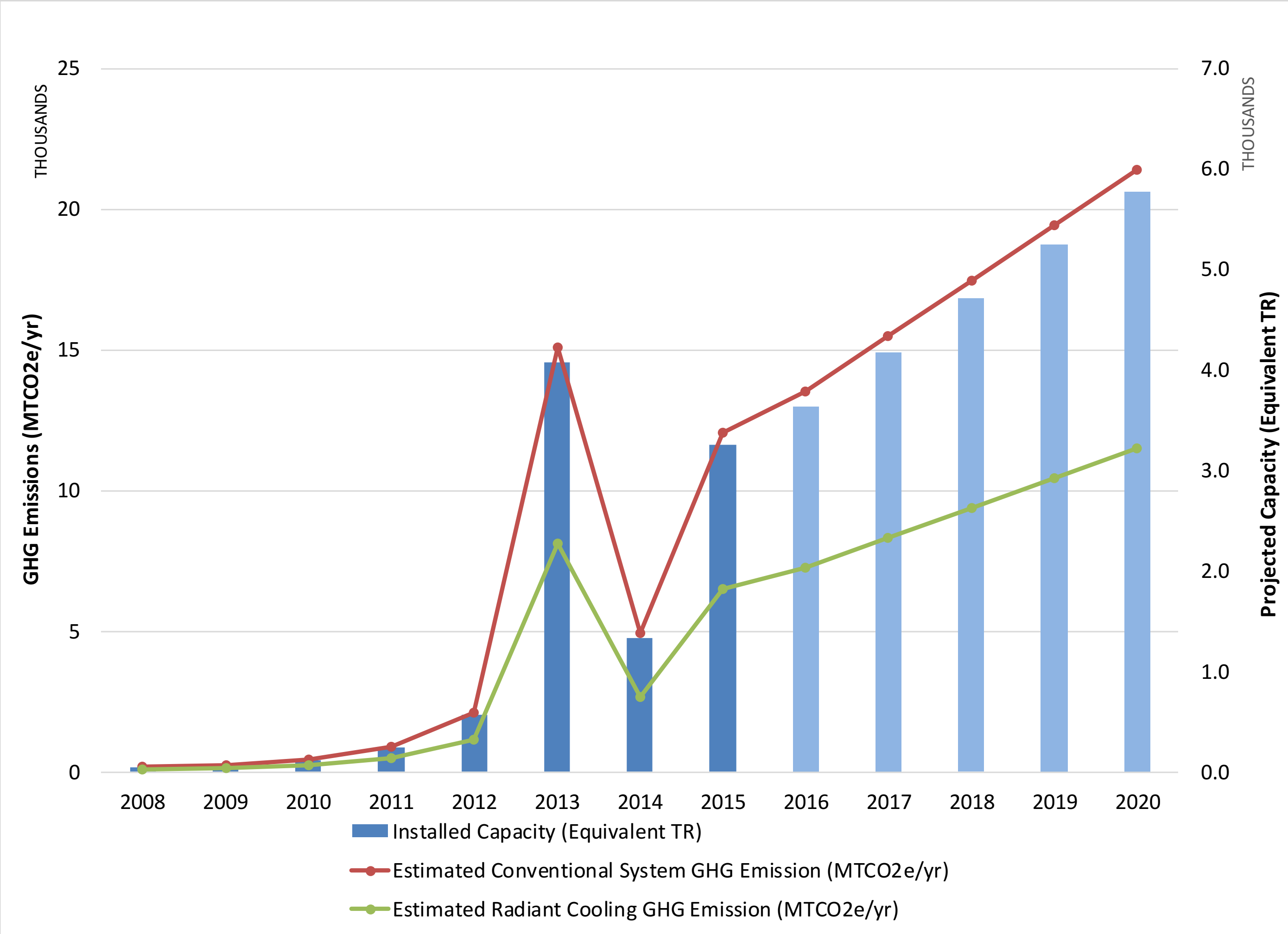
Since Radiant Cooling Systems reduce the cooling load, there is a significant reduction in GHG emissions from the complementary conventional cooling systems used under this scenario. By the year 2020, scenario suggest a 46% savings in GHG emissions. While GHG emissions from conventional systems were 39,265 MT CO_2e, GHG emissions from use of Radiant Cooling with conventional systems were estimated at 21,134 MT CO_2e from 2016-2020. In other words, 1.86 times lesser emissions from conventional systems. The corresponding figures for the period from 2016-2020 were estimated to be 87,720 MT CO_2e and 46,973 MT CO_2e respectively.

Figure 46 | Radiant Cooling Growth (TR) & Energy Consumption Projection



Source: cBalance Solutions Hub analysis

Figure 47 | Radiant Cooling Growth (TR) & GHG Emission Projection



Source: cBalance Solutions Hub analysis

2.3.2 Manufacturing Capacity

Structure Cooling

The manufacturing capacity varies on project to project bases.

Radiant Cooling

The manufacturing capacity purely depends on the scale of the project. There is no defined limit as such to the area which can be cooled using Radiant Cooling.

2.3.3 Design & Installation Capacity

Structure Cooling

The design capacity of structure cooling system range from of as low as 300sq.ft to a maximum (installed till date in India) of 1,00,000 sq. ft.

Radiant Cooling

Radiant Cooling systems have been successfully installed to cool areas as small as 500 Sq. ft. to a maximum (installed till date in India) of 4,19,000 Sq. ft.

2.3.4 Servicing Capacity

No data available.

2.3.5 Case Studies

Radiant Cooling

Uponor's Radiant Cooling Solutions, since 2009has executed several radiant cooling system based projects in India. For this study, the Infosys MC1 installation is considered. Infosys is one of the global leaders in software development and is providing information technology solutions. The company is committed to sustainable growth and in pursuit of the same, they set up a team that implements sustainable solutions.

Table 13 | Radiant Cooling Case Study - Project Details

Location	Infosys
City	Hyderabad
Area	24000 Sq.m
Occupancy	2500
HVAC System Installed	Radiant Cooling System
% of area required cooling	85%

Source: Study by Infosys Green Initiatives

The MC1 building is a new facility of Infosys with 24,000 Sq.m of area. It is a project in which the slab had already been cast; as a result, slab cooling was not an option. A radiant cooling solution was installed, that provides higher thermal performance with cross-linked polyethylene pipes embedded in a layer of highly conductive material. These comfort panels, which are connected to a centralized chilling unit, that work at higher chilled water temperatures, thus resulting in a higher coefficient of performance (COP). The sensible cooling provided by the comfort panels had also reduced the amount of air to be circulated in the conditioned space, leading to a substantial reduction of the number of air handling units and in duct size. A reduction of energy consumption is another effect resulting out of the introduction of the radiant solution.

Upon comparing the installed radiant cooling system with a conventional system, an overall energy saving of 38.9% (1,71,000 kWh/yr) was observed (*see Table 15)*. Additionally, the system not only saved energy but also cost INR 292,300 less than the conventional system (*see Table 16*). A comparison of the system details is shown in *Table 14.*

Moreover, out of the 9 case studies reviewed, the minimum energy saving of 22.2% and maximum energy saving of 65% was observed, at an average of 36.4% across all 9 reviewed projects.

Table 14 | Infosys Case Study - System details comparison

System	Conventional AC System	Radiant
Cooled Area (Sq. m)	11,600	11,600
Supply Side Chilled Water Design Temp (Deg. C)	7.8	14
Return Side Chilled Water Design Temp (Deg. C)	15.6	17
Cooling Tower Approach (Deg. C)	2.2	2.2

Source: Study by Infosys Green Initiatives

Table 15 | Infosys Case Study – Energy Savings

Building	Conventional Building	Radiant Cooled Building
HVAC Annual Energy Index (kWh/sq.m)	38.7	25.7
Efficiency of Chiller Plant (kW/TR)	0.6	0.45
Energy Consumption (kWh/yr)	4,40,000	2,69,000
Reduction in Annual Energy Index (%)		**33.6%**
Energy Savings (kWh/yr)		**1,71,000**
Energy Savings (%)		**38.9%**

Source: Study by Infosys Green Initiatives

Table 16 | Infosys Case Study – Cost Savings

Buildings	Conventional Building	Radiant Cooled Building
Chiller (INR)	31,45,200	31,45,200
Cooling tower (INR)	13,06,400	13,06,400
HVAC low side works (INR)	2,28,39,000	1,53,10,000
AHUs, DOAS, HRW (INR)	51,18,200	28,78,900
Radiant piping, accessories, installation, etc. (INR)	Nil	90,75,800
Building Automation System (INR)	61,84,000	65,84,000
Total cost (INR)	**3,85,92,600**	**3,83,00,300**
INR/Sq.m	3,327	3,302

Source: Study by Infosys Green Initiatives

Structure Cooling

Panasia Engineers have executed several projects that involve cooling through structures. This study has reviewed the Veer Savarkar Rashtriya Smarak in Dadar, Mumbai (*see annexure for images*). A detailed study reveals that after installing the system, a reduction in cooling load of 10.8 TR was observed. This led to a total energy savings of 7.69 kWh/sq.ft/yr. Importantly, a 11.2 deg C reduction in surface temperature was also observed.

Moreover, as shown in ***Error! Reference source not found.Error! Reference source not found.***, Slab B1 with a conventional cooling system reaches a peak temperature of 57 deg C, whereas Slab A1 with a structure cooling system reached 46 at the same given time. Thereby reducing load by 11 deg C. Percentage reduction in load was observed at 21%.

Across all five projects executed by Panasia Engineers, an average energy saving of 51% has been observed, with a minimum real world observed saving of 24% and a maximum of 75%.

Table 17 | Structure Cooling Case Study – Project details

Location	**Veer Savarkar Smarak**
City	Mumbai
Roof Area	554 Sq.m
HVAC System Installed	Structure Cooling System

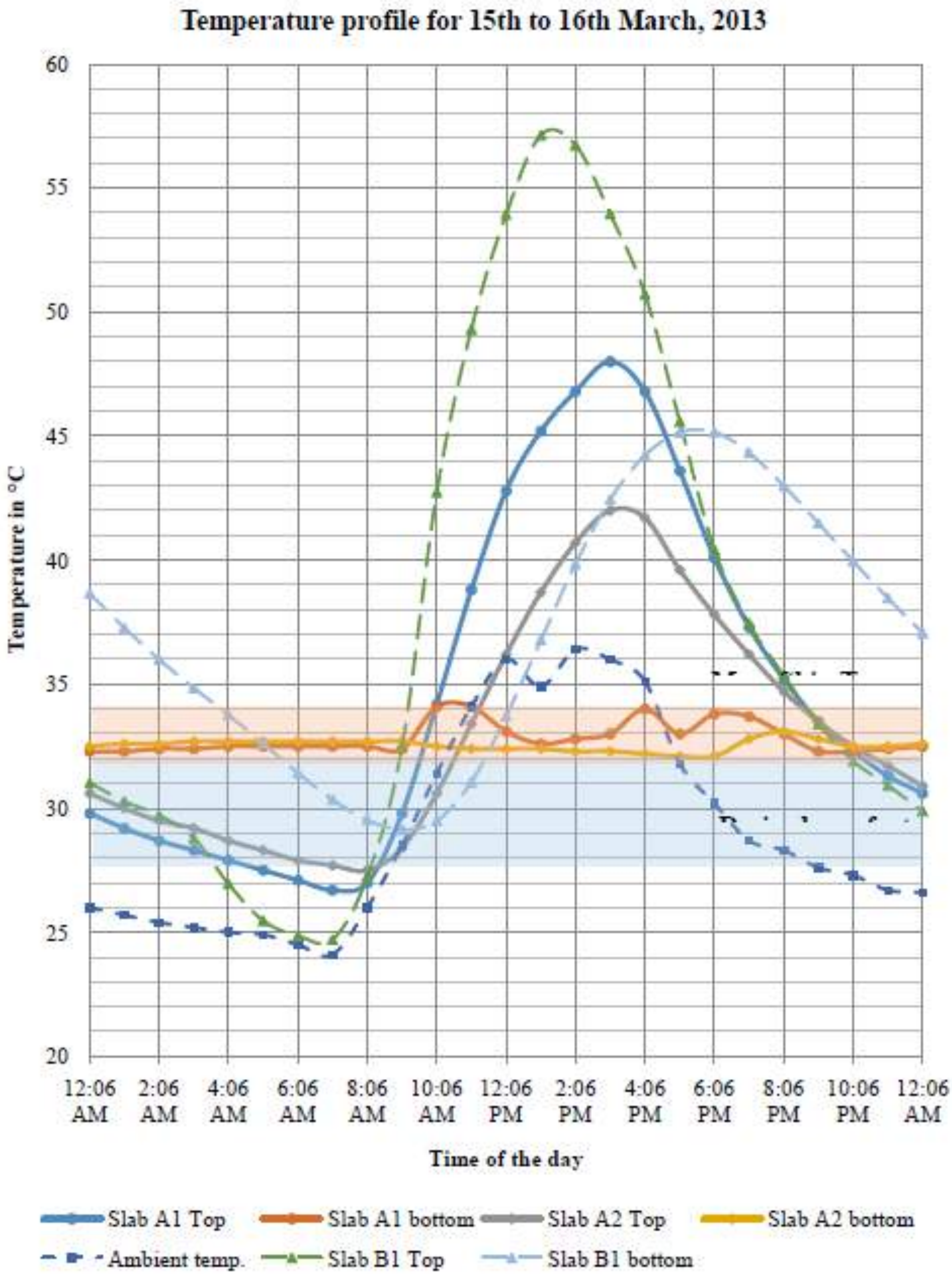
Source: Panasia Engineers

Table 18 | Structure Cooling Case Study – Savings Analysis

Systems	**Conventional System**	**Structure Cooling System**
Top Side Slab Temp (deg C)	57.1	48
Surface Temp (deg C)	45.2	34
HVAC System Tonnage (TR)	51.4	40.6
Energy Consumption (kWh/sq.ft/year)	10.8	3.1
Reduction in Surface Temp (deg C)		**11.2**
Reduction in HVAC System (TR)		**10.8**
Energy Savings (kWh/sq.ft/yr)		**7.69**

Source: Panasia Engineers

Figure 48 | Structure Cooling Case Study: Temperature Profile



Source: Panasia Engineers

2.4 Direct/Indirect Evaporative Cooling

2.4.1 Current Uptake Scenario

2.4.1.1 Applicable Sectors

Indirect and Direct Evaporative Cooling systems are also implemented primarily across the stationary Airconditioning (residential & commercial) sector.

2.4.1.2 Installed/Sold Capacity

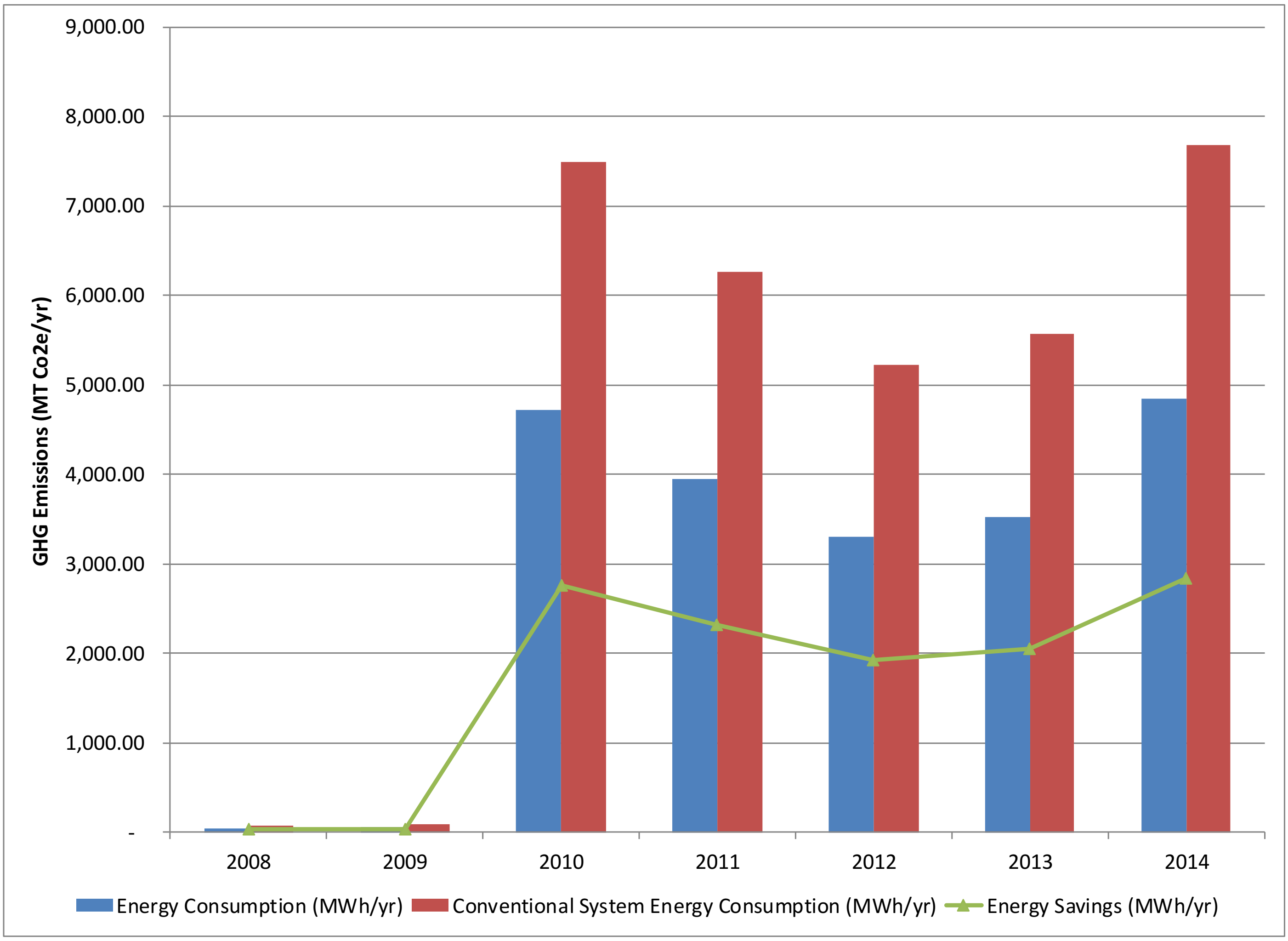
Tonnage

As per data received from four manufacturers of IDEC systems from 2008 till March 2014, an aggregate of 1,80,42,769 CFM System has been installed/sold. This is approximately 11,103 TR.

GHG, power & energy consumption and savings

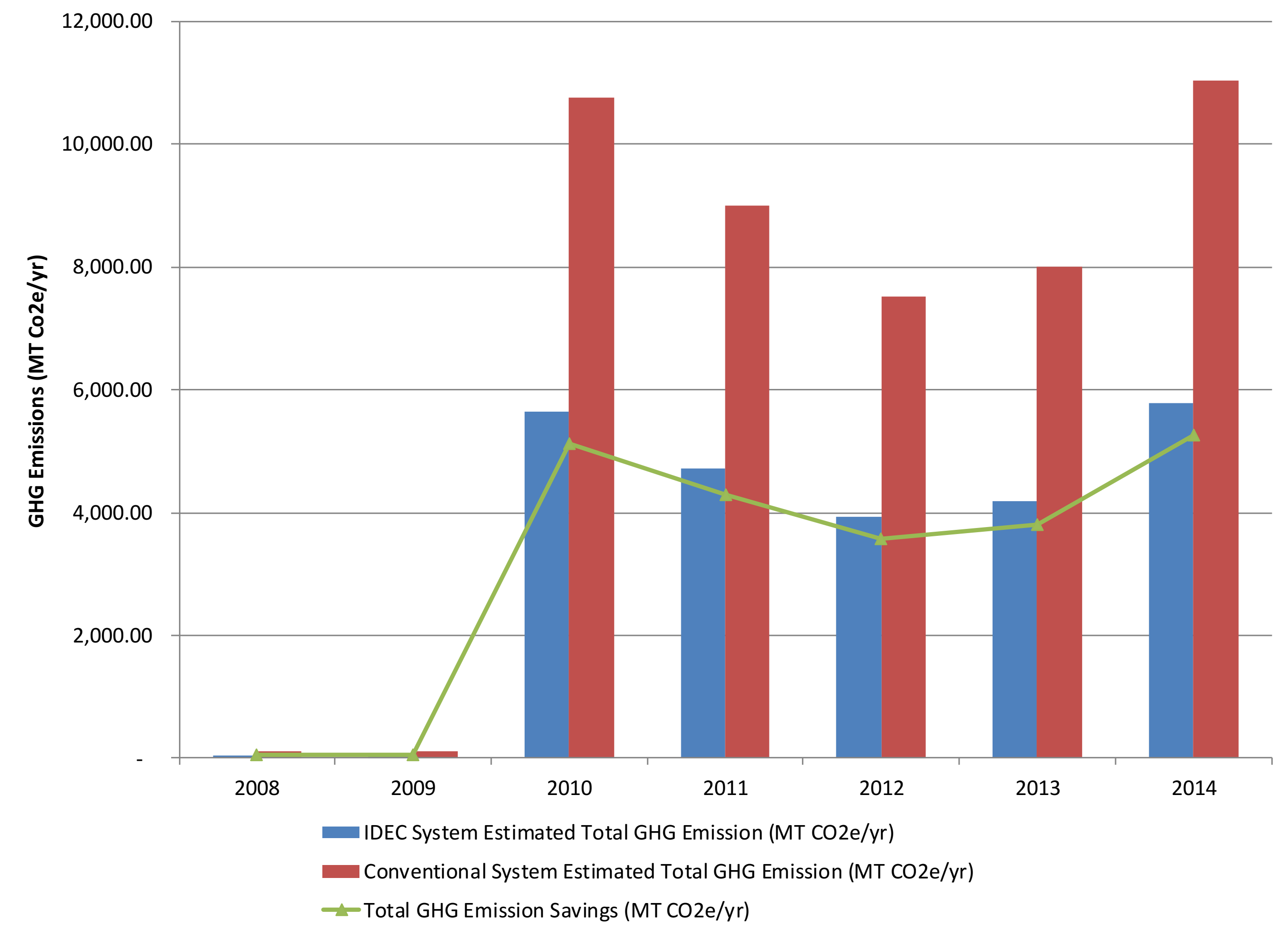
Until March 2014, power consumption from installed IDEC systems was estimated to be 9,160 kW, while that from conventional systems was 14,512 kW, higher by 58.4%. Similar trend line was observed for energy consumption, IDEC was estimated at 20,445 MWh/yr and conventional systems were estimated at 32,391 MWh/yr. A total of 22,178.9 MT CO_2e of GHG emissions were estimated to be avoided through IDEC systems from 2008 to March 2014.

Figure 49 | Energy Consumption: Conventional System vs IDEC System



Source: cBalance Solutions Hub analysis

Figure 50 | GHG Emissions: Conventional System vs IDEC System



Source: cBalance Solutions Hub analysis

2.4.1.3 Growth Projection

Assumptions

- For comparison purposes, conventional AC system is assumed to be a 3-star AC (most widely used AC in the residential sector in India) with a COP of 3.05 as the baseline
- Conventional system specifications: average refrigerant mix.; medium &large commercial refrigeration; capacity range 45 to 1770 TR; avg. efficiency
- Electricity GHG emissions (includes T&D losses) 1.19 kg CO2e/kWh
- IDEC Power Consumption = 0.8 kW/TR
- Scenario 1 -growth projections has been done through polynomial Equation based on past data.

Tonnage

Under this scenario, 2,33,33,433 TR is estimated to be installed, 5 times more than 2014 levels as seen in *Figure 52*.

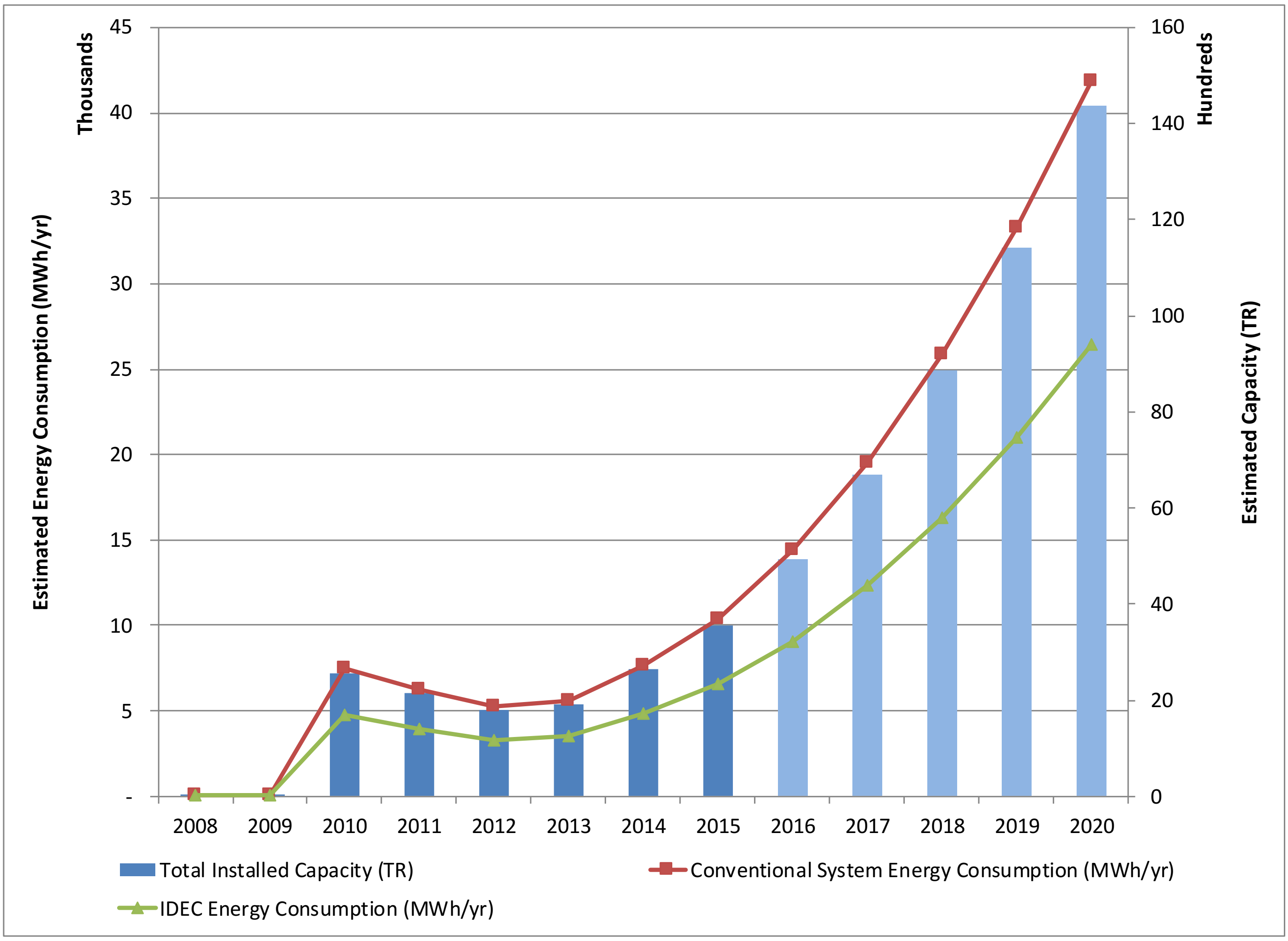
Power and Energy Consumption/Savings

Estimations from scenario showcased significant power and energy savings up till 2020. Savings till 2020 were estimated to be 29,357kW. Energy saved till 2020 from use of IDEC systems is estimated to be 65,526 MWh/yr.

GHG Emissions

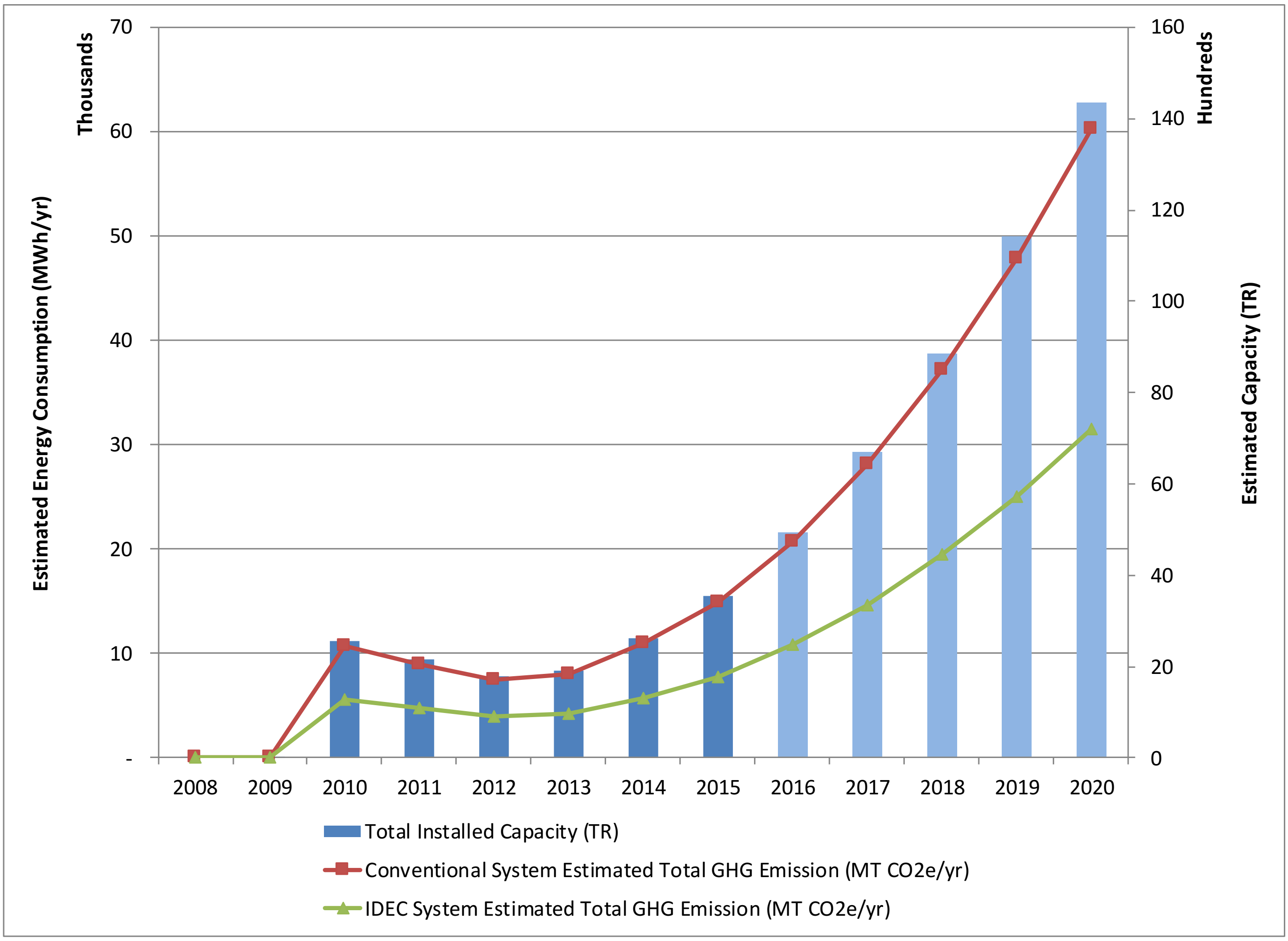
As highlighted in section 2.4.1.2, since GWP and ODP for IDEC system are zero, there is a significant reduction in GHG emissions under this scenario. By the year 2020, scenario suggest a 47% savings in GHG emissions. While GHG emissions from conventional systems were 2,55,443 MT CO_2e, GHG emissions from IDEC systems were estimated at 1,33,784 MT CO_2e. In other words, 2.1 times less than emissions from conventional systems.

Figure 51 | IDEC System Growth (TR) & Energy Consumption Projection



Source: cBalance Solutions Hub analysis

Figure 52 | IDEC System Growth (TR) & GHG Emission Projection



Source: cBalance Solutions Hub analysis

2.4.2 Manufacturing Capacity

The manufacturing capacity of HMX is 1,20,00,000 CFM annually

2.4.3 Design & Installation Capacity

The design capacity of IDEC systems range from as low as 1,000 CFM to a maximum (installed till date in India) of 1,45,000 CFM.

2.4.4 Servicing Capacity

No data available

2.4.5 Case Studies

2.4.5.1 ICC, Devi Gaurav Tech Park, Pune – HMX (Case study 1)

As highlighted in *Table 20 Table 22*, a comparison of the installed Indirect/Direct Evaporation system (IDEC) system with a conventional evaporative system reveals that there was a savings in net water addition during summers and monsoon season of 71% and 65% respectively. Moreover, the IDEC system also led an energy saving of INR 1,72,800/yr and 21,600 kWh/yr.

Table 19 | IDEC Case Study 1 – Project Details

Location	Devi Gaurav Tech Park
City	Pune
Area	18,000 Sq.ft
Height	30 ft
Temp required	30 Deg C
HVAC System Installed	Indirect Direct Evaporative Cooling System
Fresh Air (%)	**100%**

Source: HMX-ATE

Table 20 | IDEC Case Study 1 – Savings Analysis

System	Evaporative Cooling System	IDEC System
Air Requirement(CFM)	1,20,000	80,000
Humidity in Space	High	70% Less
Summer - Net water addition in supply air (l/hr)	1750	500
Monsoon - Net water addition in supply air (l/hr)	650	225
Power consumption (kW/1,000 CFM)	54	48
Energy Consumption (kWh/yr)	1,94,400	1,72,800
Energy Cost (INR/yr)	15,55,200	13,82,400
Ducting Cost (INR)	42,00,000	28,00,000
Savings in net water addition during summers		**71%**
Savings in net water addition during monsoons		**65%**
Energy Savings (kWh/yr)		**21,600**
Energy Cost Savings (INR/yr)		**1,72,800**
Duct Installation Savings (INR)		**14,00,000**
Operation Cost Savings		**11.11%**

Source: HMX-ATE

2.4.5.2 NCMR Infonet – Bengaluru (Case study 2)

As highlighted in *Table 22*, a comparison of the installed IDEC system with a conventional AC System reveals that the total energy cost savings accounted for INR 1,70,000/yr and project savings accounted for INR 1,00,000. A 66.40% savings in operation cost were additionally observed. A comparison study of estimated emissions from a conventional AC system and the installed IDEC system suggests that 35,870 kg of CO_2, 220 kg of SO_2, 59 kg of NO_2, and 27 kg of SPM would additionally be abated due to the installation of the IDEC system.

Table 21 | IDEC Case Study 2 – Project Details

Location	NCMR Infonet
City	Bengaluru
Area	2,000 Sq.ft
HVAC System Installed	IDEC
Fresh Air (%)	100%

Source: TERI, GTZ and EMC

Table 22 | IDEC Case Study 2 – Savings Analysis

System	Conventional AC System	IDEC System
TR Estimated	16	
Air Requirement (CFM)		6000
Demand Requirement (kVA)	25	8
Energy Consumption (kWh/yr)	51,200	17,100
Energy Cost (INR/yr)	2,56,000	86,000
Project Cost (INR)	5,00,000	4,00,000
Energy Savings (kWh/yr)		34,100
Energy Cost Savings (INR/yr)		**1,70,000**
Project Savings (INR)		**1,00,000**
Operation Cost Savings		**66.40%**

Source: TERI, GTZ and EMC

Table 23 | Conventional System comparison with IDEC - Emissions

System	Conventional AC System	IDEC System
CO2 (kg)	53,858	17,988
SO2 (kg)	330	110
NO2 (kg)	88	29
SPM (kg)	40	13

Source: TERI, GTZ and EMC

2.5 Ammonia (NH_3) and CO_2 Food Refrigeration

2.5.1 Current Uptake Scenario

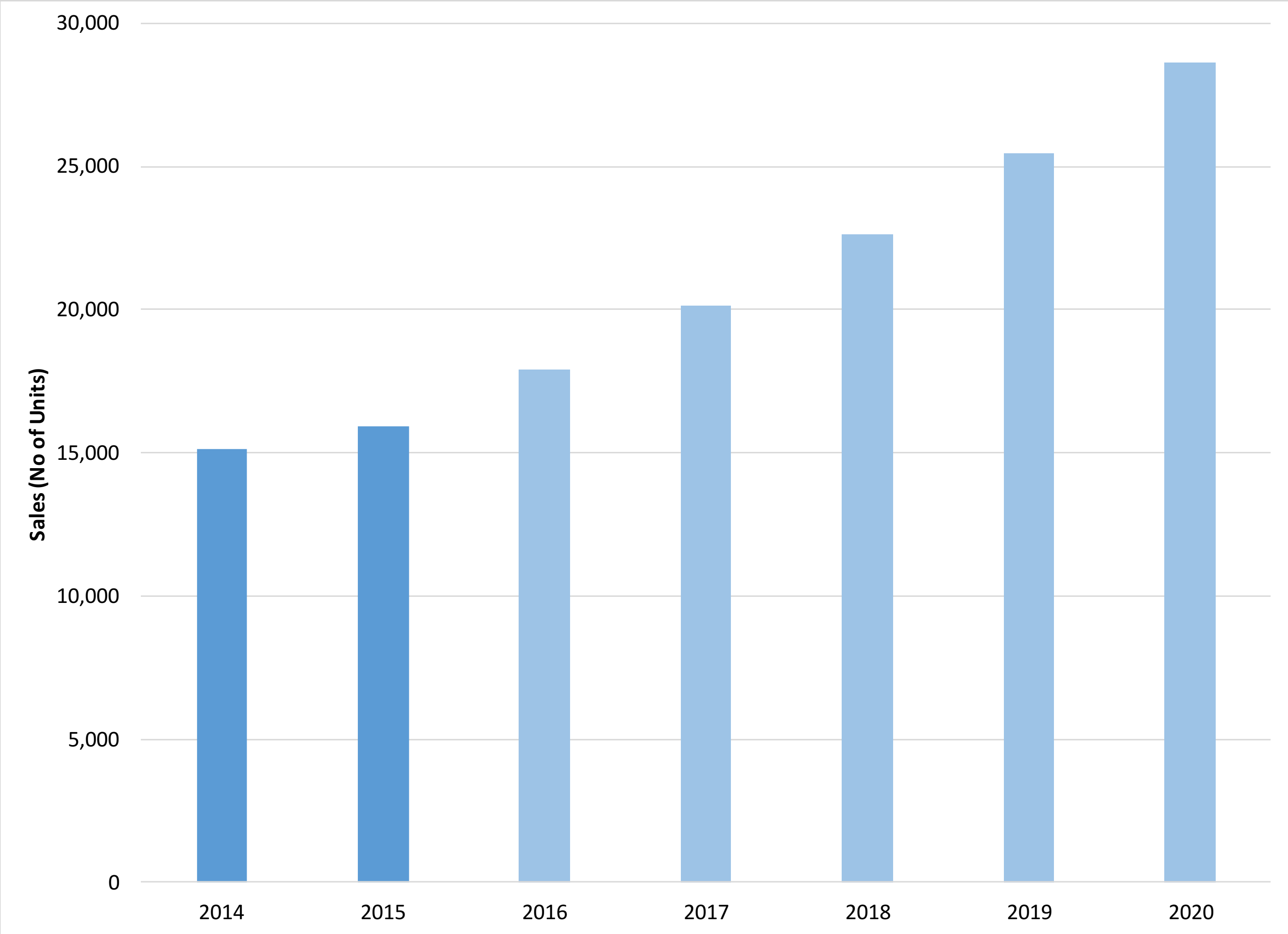
2.5.1.1 Applicable Sectors

Refrigeration across commercial and Industrial sectors. The range of equipment covered include reach-in coolers, process chillers, milk chillers, cold storage and ice-cream machines.

2.5.1.2 Installed/Sold Capacity

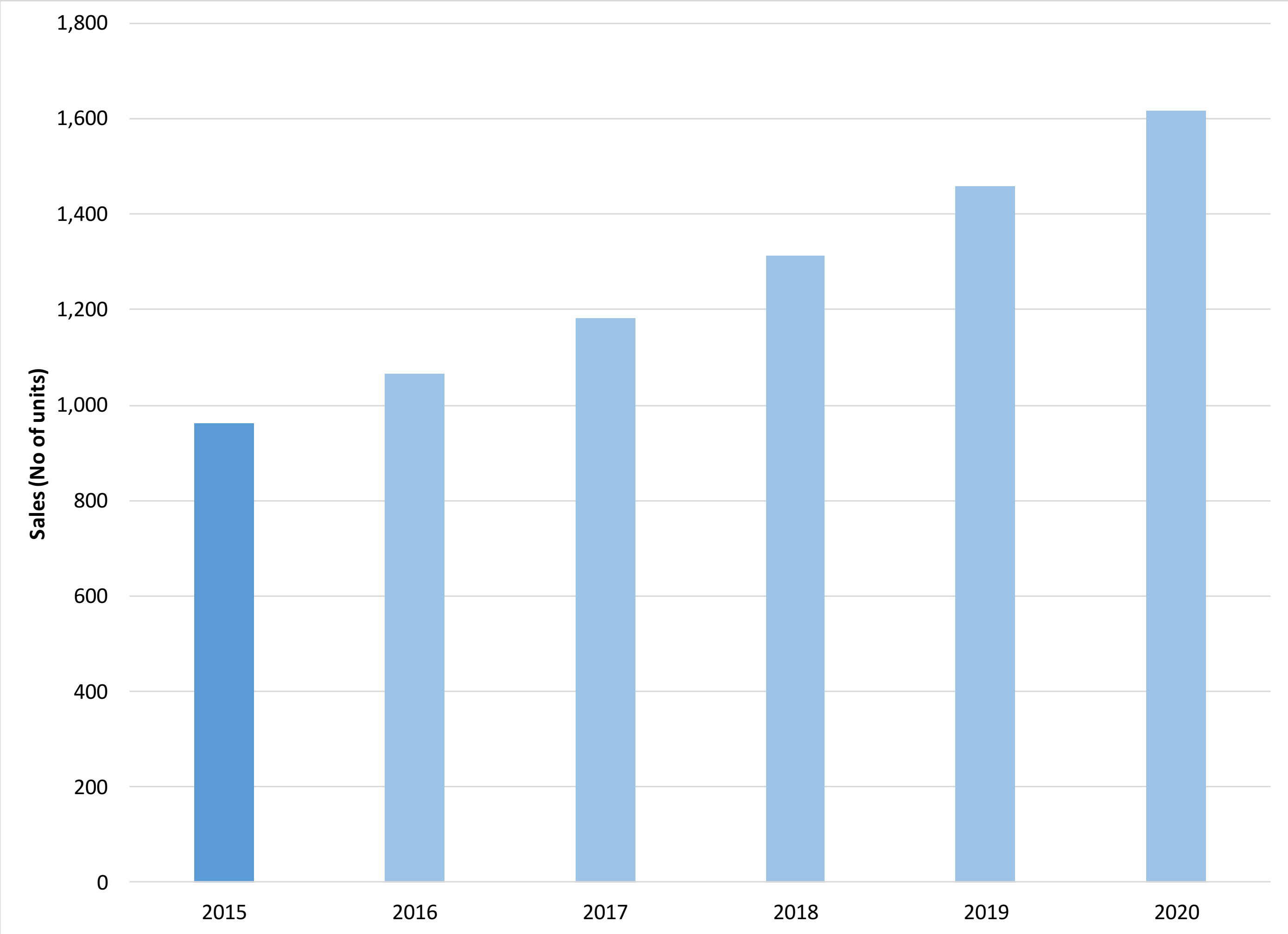
Due to lack of data, general figures received from interactions with ISHRAE, RAMA and other industry stake-holders were used. Annual sales of CO_2 based reach-in coolers were approximately 15,000 units in 2014 and are estimated to reach 28,652 units in 2020. 960 units of NH_3 based process chillers have been sold in 2015, which is approximately 1,68,000 TR and the annual sales are expected to rise to 1546 units in 2020. For milk chillers using ammonia as the refrigerant, 917 units were sold in 2010, which is equivalent to approximately 34,388 TR. Using an industry specified CAGR of 10% between 2010-2015, the cumulative sales in this period amount to 7000 units. Similarly, using the CAGR for 2015-2020, 9913 units are estimated to be sold between 2016-2020. In 2015, 240 NH_3 based cold storage units were sold and the sales are expected to cross 400 units per year by 2020. Besides NH3 and CO2, ice-cream machines using R290 refrigerant have also sold approximately 5000 units each in 2014 and 2015 with a total of 39,600 units expected to be sold till 2020.

Figure 53 | Sales Projections for CO_2 Reach-in Coolers



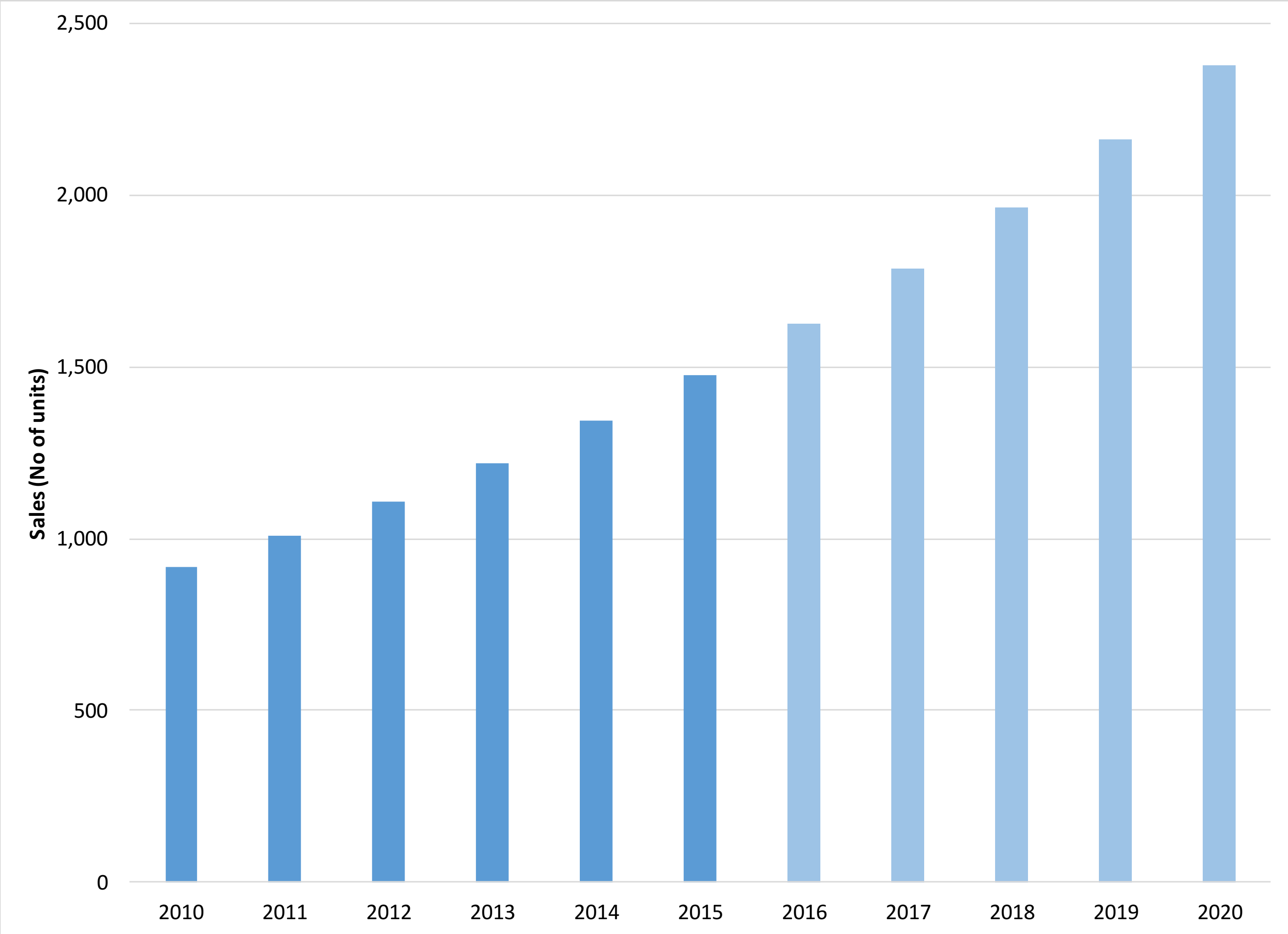
Source: cBalance Solutions Hub analysis

Figure 54 | Sales Projections for NH_3 Process Chillers



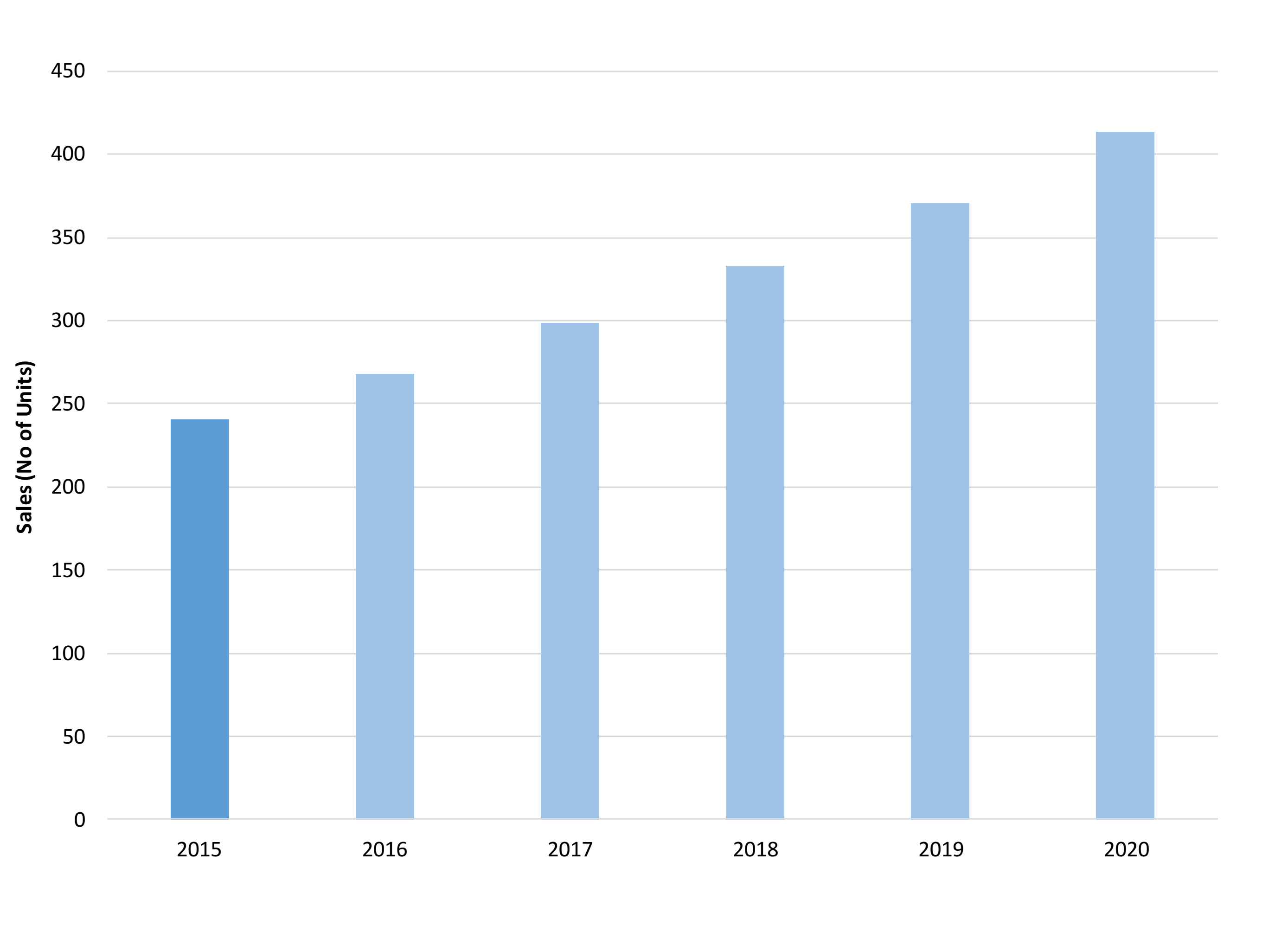
Source: cBalance Solutions Hub analysis

Figure 55 | Sales Projections for NH_3 based Milk Chillers



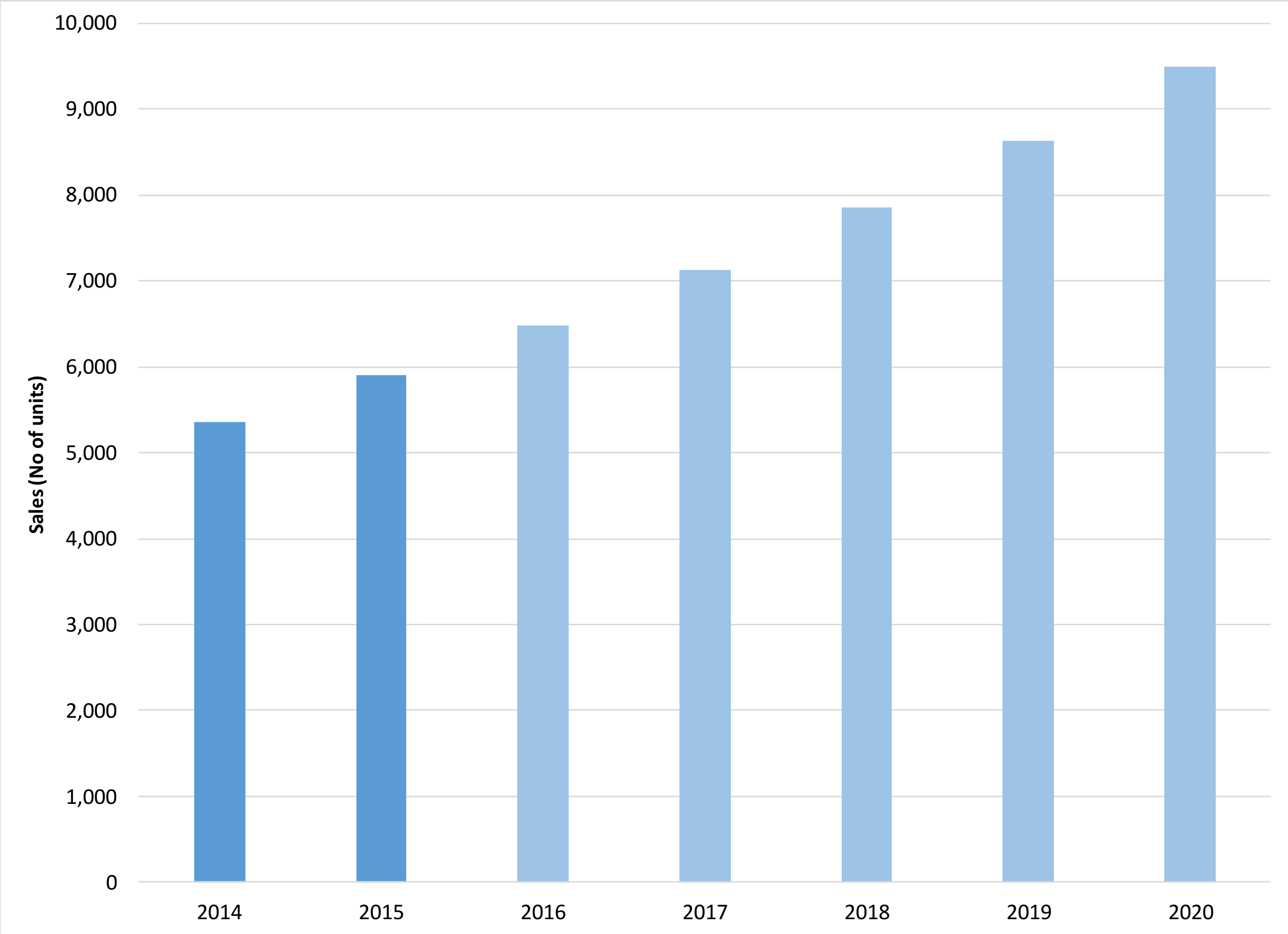
Source: cBalance Solutions Hub analysis

Figure 56 | Sales Projections for NH_3 based Cold Storage Units



Source: cBalance Solutions Hub analysis

Figure 57 | Sales Projections for R290 based Ice cream machines



Source: cBalance Solutions Hub analysis

2.5.1.3 Growth Projection

2.5.2 Manufacturing Capacity

No data available

2.5.3 Design & Installation Capacity

2.5.4 Servicing Capacity

No data available

2.5.5 Case Studies

2.6 Comparison between conventional & natural refrigerant based technologies

Centred on data gathered from over 100 manufacturers for the purpose of this study, a comparative analysis between conventional systems and natural refrigerant based technologies was carried out to realise the capital costs, energy consumption & savings, GHG savings, and payback period of both technologies. An estimated capacity of 38 TR is considered. See *Table 24* for EER specifications. This comparative assessment culminates in a macro-level Marginal Abatement Cost Curve (MACC) Analysis. Results are highlighted under the following sections.

Table 24 | EER specifications of conventional & natural refrigerant based technologies

SYSTEM TYPE	EER
TR	38
3 Star Conventional System	3.07
Indirect - Direct Evaporative Cooler Details	4.62
5 Star Air Conditioning Details (Conventional Refrigerant)	3.40
6 Star Air Conditioning Details (Refrigerant - R290)	3.7
Radiant Cooling	30% (Increase in EER Percentage - *Based on case study and available manufacture data*)
Structure Cooling System	3.93

Source: cBalance Solutions Hub analysis

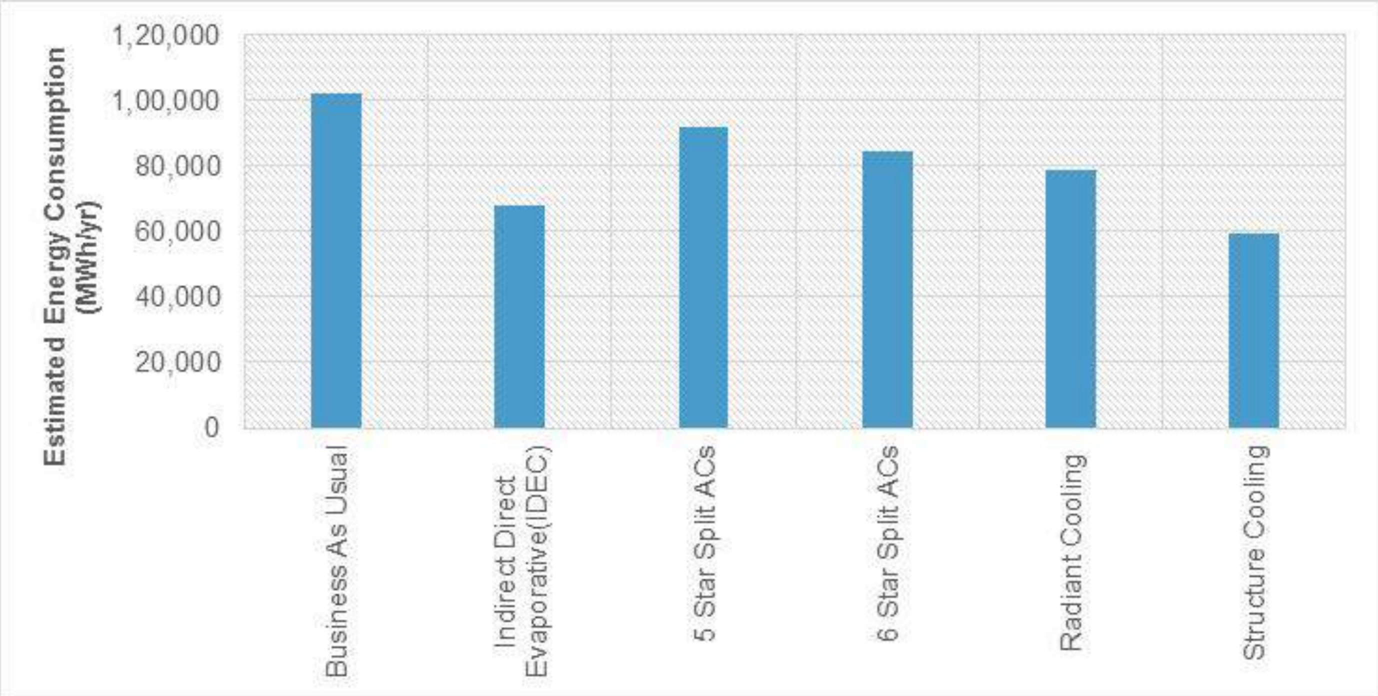
MACC Curves: An enterprise-specific Marginal GHG Abatement Cost Curve (MACC) analysis is a key component of an institutionalized Sustainability Strategy. It is designed to discover the most cost-effective means of mitigating climate change impact through technological interventions or modifications in management practices. It is a vital decision-support input for planning capital expenditure on Energy Efficiency, Water Conservation, Waste Reduction & Management etc. projects in a manner that safeguards the financial sustainability of the Organization while achieving tangible environmental and socio-economic sustainability benefits for the planetary ecosystem. The idea is to harvest the low-hanging fruits first, accumulate the economic benefits from these no-regret options and then steps through more challenging interventions. In this way, it reduces financial risk and ensures longevity of the environmental program at large.

MACC Methodology: Costs and benefits are calculated based on real values of financial parameters such as inflation, interest rates, cost of electricity, energy etc. and resource conservation benefits of options reflect the enhancement in technological alternatives available over time.

2.6.1 Energy consumption

Evidently, for the same amount of tonnage, business-as-usual, i.e. a conventional cooling system, consumes the maximum energy of 1,01,867 MWh/yr. This is 1.7 times more than a structure cooling based system, which consumes only 58,982 MWh/yr. The analysis clearly suggests that all natural refrigerant based technologies consume less energy than conventional systems. Furthermore, R290 based ACs, i.e. 6 Star Split AC, consume 17,345 MWh/yr less than a BAU AC system (*see Figure 58*).

Figure 58 | Energy Consumption - Conventional & Natural Refrigerant based technologies

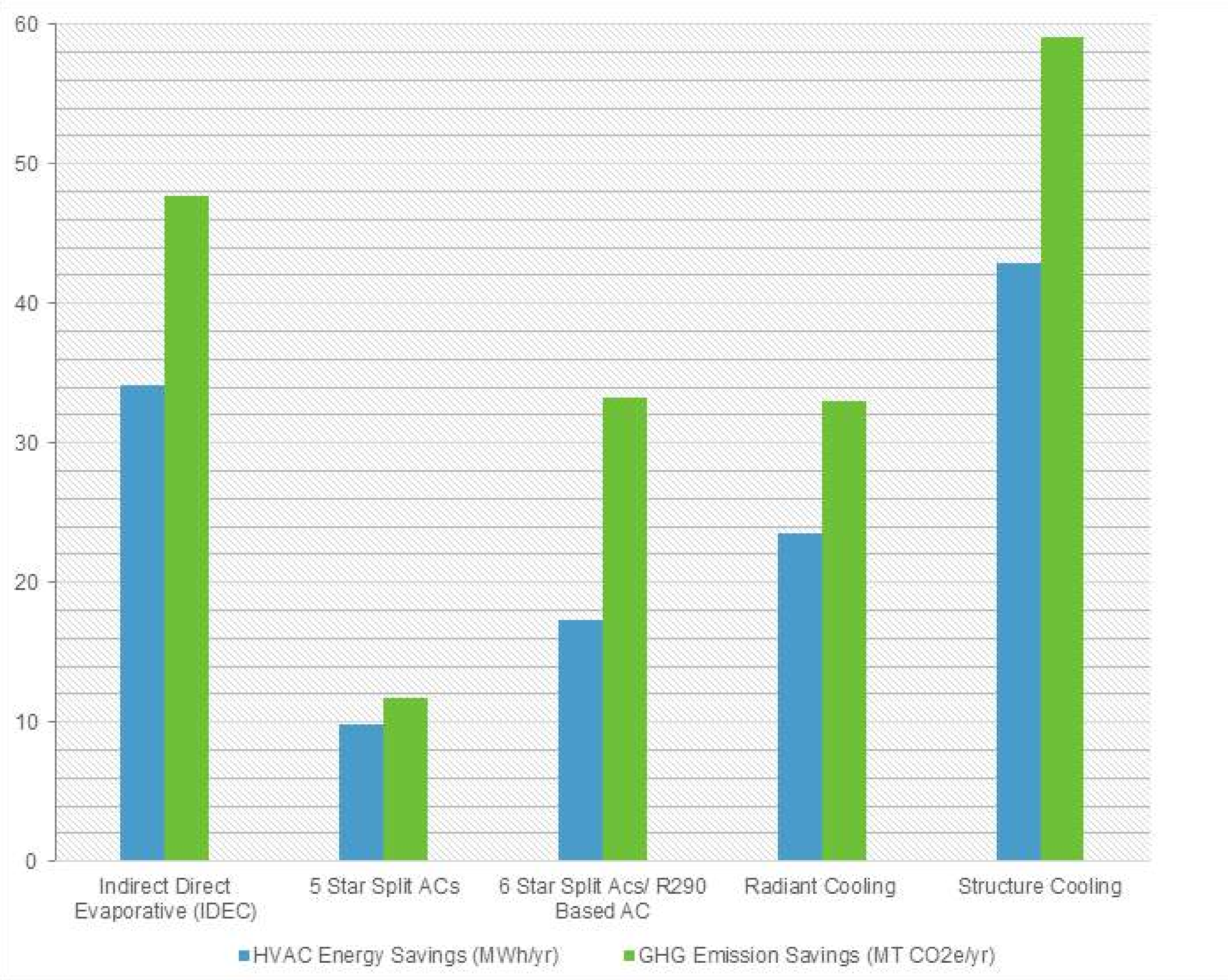


Source: cBalance Solutions Hub analysis

2.6.2 Energy & GHG Savings

Upon comparing BAU system (a conventional AC system) with NRTs, it is apparent that all NRTs provide significant energy and GHG savings. Structure Cooling provides the maximum energy and GHG savings of 59.1 MWh/yr and 43 MTCO2e/yr respectively, following by IDEC with energy and GHG savings of 47.7 MWh/yr and 34 MTCO2e/yr. The least amount of savings was observed for the conventional refrigerant based 5 star split AC. (Refer *Figure 59*)

Figure 59 | Energy & GHG Savings – Natural Refrigerant based technologies

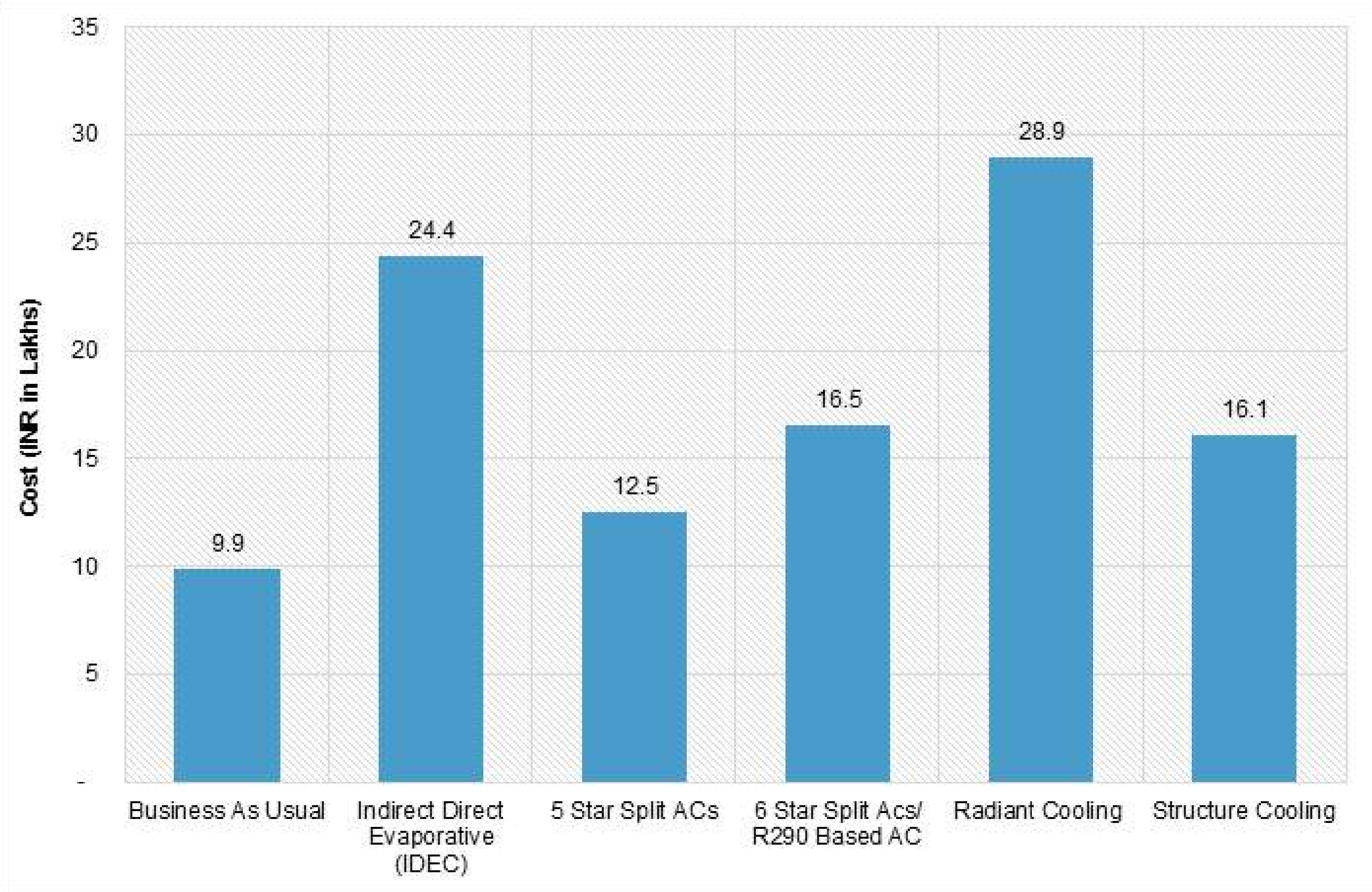


Source: cBalance Solutions Hub analysis

2.6.3 Capital Costs

While the savings are significant, it is important to understand the financial implications of these systems. For this purpose, a capital cost comparison is provided, *see Figure 60*. BAU or a conventional system of 38 TR capacity as expected had the least capital cost of INR 9.9 lac followed by 5 star split AC at 12.5 lakhs for a similar TR capacity. Radiant cooling being the most expensive at 28.9 Lakhs is almost three times more expensive than the BAU scenario.

Figure 60 | Capital Costs - Conventional & Natural Refrigerant based technologies

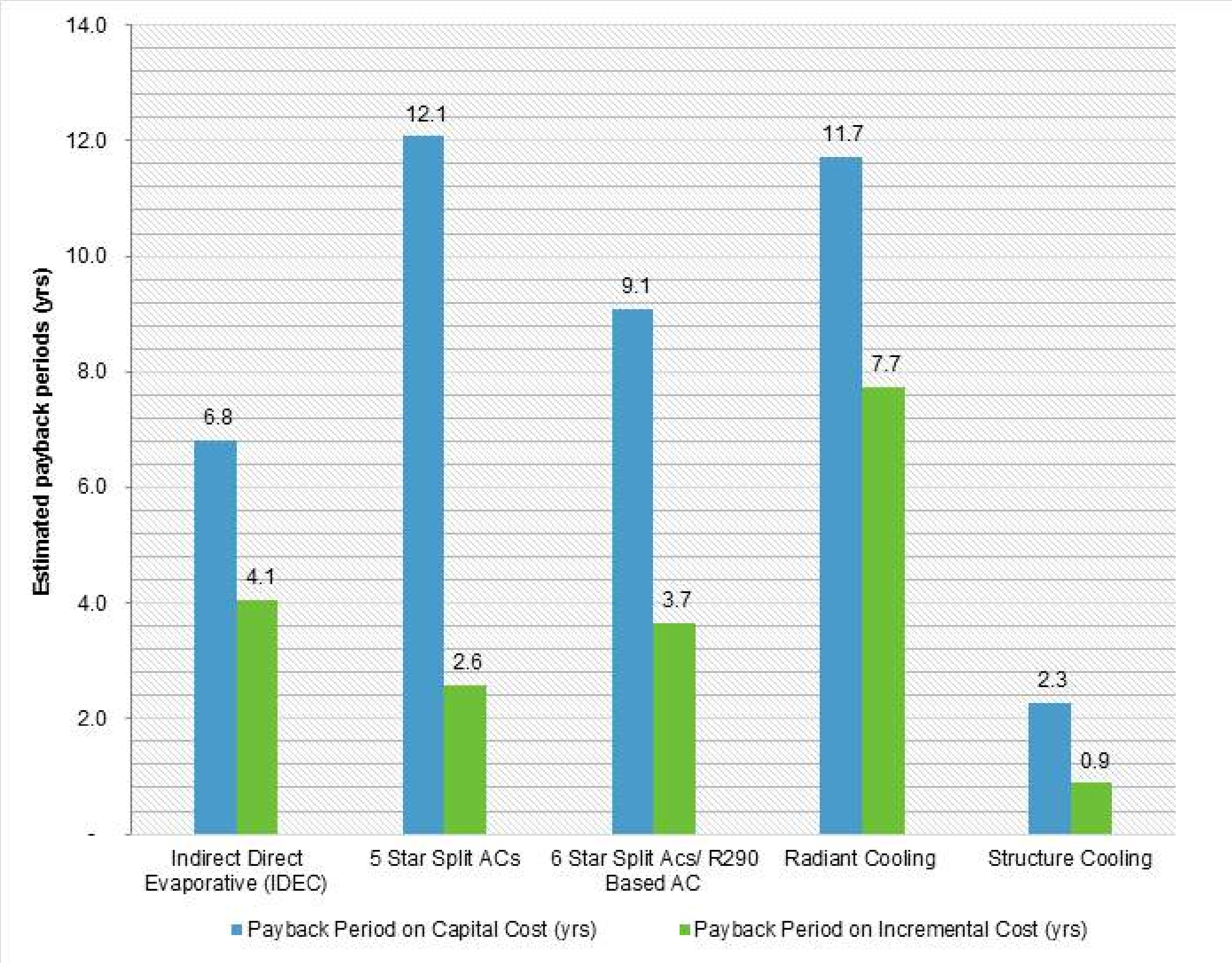


Source: cBalance Solutions Hub analysis

2.6.4 Payback period

Comparisons on Capital cost highlighted that all NRTs are currently more expensive than a BAU system and a 5 star split AC system. However, on analysing the payback period, it is evident that a 5 star split AC has the longest payback period on capital cost of 12.1 yrs. while, the payback period on incremental cost for a structure cooling system is as short as 0.9 years and payback period on capital cost is 2.3 years. The maximum payback period from NRT systems is observed for the Radiant Cooling system, where payback on capital cost is 11.7 yrs and from incremental cost is 7.7 yrs. Even though the payback periods are high for NRTs, with growth in uptake and further development of technology, it is bound to shorten. Needless to say, these are already good alternatives that are feasible considering the Energy and GHG abatement potential offered especially when the money effects from catastrophic climate change greatly outweigh the cost of implementing these systems.

Figure 61 | Payback Period - Conventional & Natural Refrigerant based technologies



Source: cBalance Solutions Hub analysis

2.7 Sectorial Potential of Natural Refrigerants

While growth projections have been appraised throughout earlier section(s), in order to appraise the future of natural refrigerants in India, a sectorial analysis was carried out to identify the potential of natural refrigerants till 2030. However, certain assumptions were taken into consideration before realising the potential of NRs, that will be discussed. Three key sectors were considered for analysis: Commercial Refrigeration and Stationary Airconditioning (residential & commercial), findings of which are discussed in the following sub-sections.

2.7.1 Commercial Refrigeration

The sub-sectors considered for analysis include: Remote Condenser Reach-in Cooler (RCRC); Integrated Reach-in Cooler; Water Coolers; Process Chillers and Milk Chillers. The potential of R744 (CO_2), the only NR currently adopted under the RCRC sector remains unchanged from the estimated consumption in 2015 at 60%. This is primarily due to restrictions that accompany CO_2 as a refrigerant, these are: a) CO_2 is not effective in higher ambient regions; R744 transcritical systems are not suitable for high ambient areas (e.g., Southeast Asia) where the system will always run above the critical point because of the inefficiency of transcritical operation (efficiency would be low) (Source-Emerson Climate Tech); b) Complexity of systems mean higher cost of components, increased probability of poor performance & reliability; and b) R744 has 3 to 4 times higher vapour pressure compared to conventional refrigerants; which essentially translates to a safety concern.

Under the water coolers sub-sector, R600A has the potential to entirely replace R134A with a maximum potential of 100%. This can be made possible due to the excellent thermodynamic properties of R600A leading to high energy efficiency as well as its ability to operate at significantly lower pressures than R12 or R134A. Moreover, there is already one such installation in Europe (http://www.oasis.ie/wp-content/uploads/2012/11/Brochure-ecooler-EN.pdf), and there could be many such instances in future, in India. Refrigerant use under the process chillers sub-sector currently consists (in 2015) of 4.9% Ammonia (R717) and 95.1% R134A, however, the potential of R717 is effectively 100% in the near future not considering the financial implications of such a transition as R717 has already been proven to work in the sector and has no limitations with respect to capacity of the refrigeration system. The milk chillers sub-sector already uses only Ammonia as a refrigerant.

2.7.2 Stationary Residential & Commercial Airconditioning

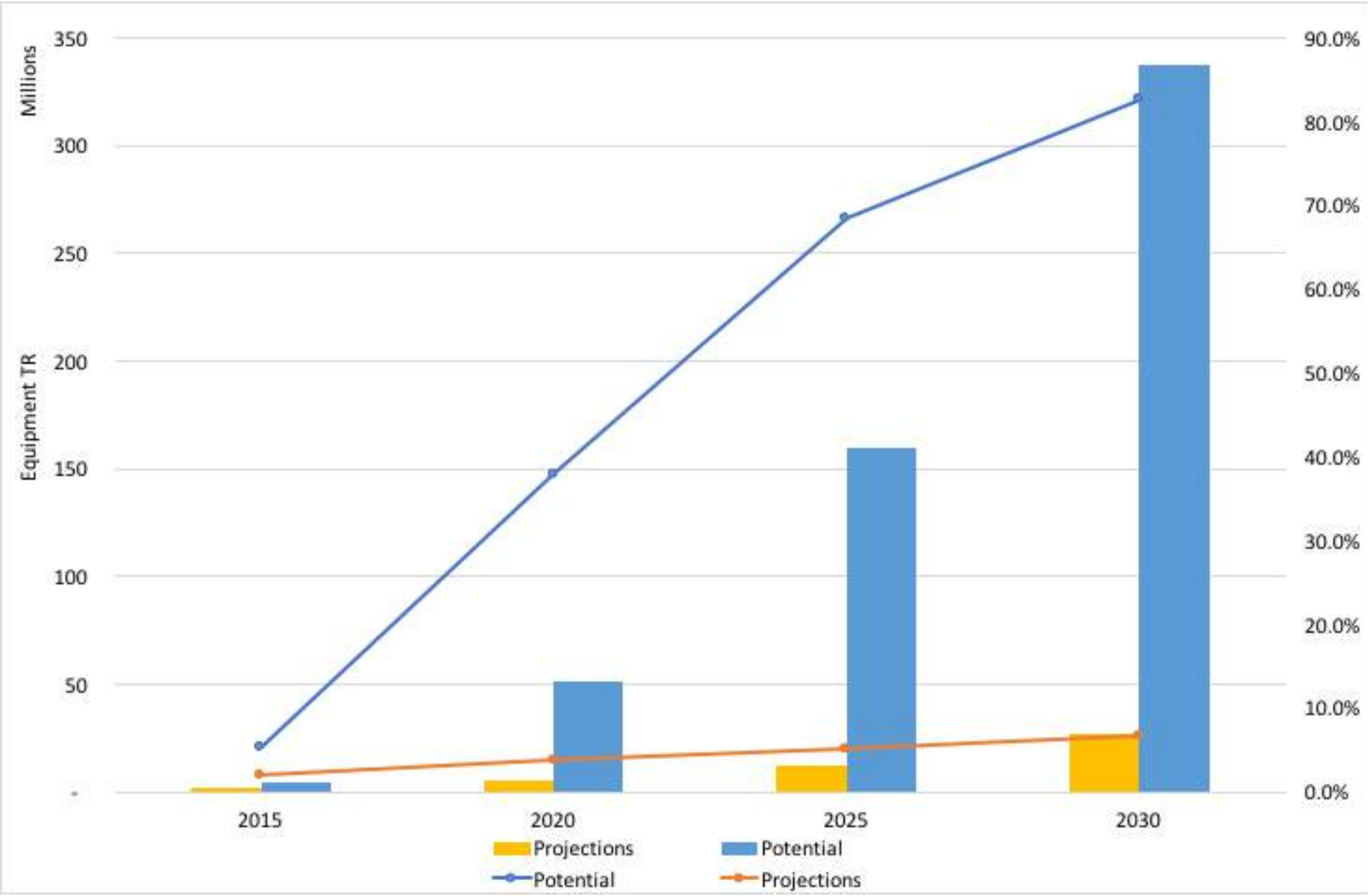
Unsurprisingly, consumption of natural refrigerant R290 under this sector sector in 2015 accounted for only 2.8% as compared to 81% from R22, 1.6% from R123, 9.7% from R410A, and 4.9% from R32. Currently, to appraise the potential of R290 in the vast and varied RAC sector, both split and window, R290 based AC units of 1 and 1.5 TR capacity (Godrej, the only manufacturer of R290 based ACs in India, manufacturers only 1 and 1.5 TR ACs as of today) were considered for the analysis. As per estimates, in 2015, under the RAC sector, 1 and 1.5 TR systems constituted 16.7% and 62.7% of the entire market share in the sector, while 2 TR systems constitute 20.7% market share. Since R290 systems can potentially replace only 1 and 1.5 TR systems, the estimated potential of R290 in this sector is 79.33%. Currently it is not possible to manufacture 2 TR systems due to the imposed charge limit owing to flammability concerns, which in turn limits the capacity of the equipment to 1.5 TR. Therefore, the entire fleet of window/split units in the capacity range under 1.5 TR could potentially be replaced by R290. Presently, there is no natural refrigerant replacement for other stationary AC units like floor mounted units and cassettes.

There are currently no viable NR replacements for DAC/PAC and VRF Airconditioning systems. However, potential of Ammonia (R717) and Lithium Bromide (LiBr) under commercial chillers is 100%, similar to conditions defined under process and milk chillers.

2.7.3 Potential Vs Growth

A comparative analysis of NR projection and their potential suggests a significant difference in what currently is and what can be in future, as well as the potential of GHG emission abatement contributing a great deal to climate change mitigation. Under the BAU scenario, NR projections for market share increase negligibly from 1.9% in 2015 to 6.6% in 2030. Whereas, the potential grows significantly from 5.3% in 2015 to 37.9% in 2020 and from 68.5% in 2025 to 82.6% in 2030. It is to be noted that while technical limitations of adopting NR have been considered in appraising the potential, financial implications have not been considered owing to involvement of factors such as varying capital expenditure, market conditions, expenditure on R&D, etc.

Figure 62 | Natural Refrigerants Market Share - Potential Vs Growth Projection



Source: cBalance Solutions Hub analysis

03

3 Conclusions

3.1 Current Perceptions and Constraints

Currently, the uptake of natural refrigerants and sustainable cooling technologies in India is limited, yet the potential is remarkable. The home automation market in India is growing at a CAGR of 30% and the cold chain and refrigeration growing at a CAGR of 25% (ISHRAE, 2016). In order to leapfrog from F-gases to natural refrigerants, focus of various stakeholders, such as: Indian industries, experts, researchers, consumers, decision makers, agencies, etc. needs to be channelled towards short and long-term social, economic, and environmental benefits of natural refrigerants and sustainable refrigeration technologies (ATMOsphere, 2010).

According to a survey carried out by Souvik Bhattacharya, IIT Kharagpur in 2010, 81% of the industry experts were aware about the existing natural refrigerants technologies in India and 72% of the experts agreed to the fact that India will need to leapfrog to natural refrigerants from HCFCs skipping the use of the intermediary HFCs altogether. The survey was conducted among leading industry consultants, experts and academia researching in the field of HVAC&R. Of the total responses, 35% were from industry experts and 65% of the responses were from academia. They were questioned on: (i) awareness towards the fact that we need to switch to Natural Refrigerant based systems (e.g. CO_2 based systems) owing of the environmental issues? (ii) were they aware that such refrigerants and technologies are already available and a host of manufacturers exists globally to supply such green systems? (iii) CO_2 based systems in supermarkets are becoming a reality in Europe, Australia, etc. Did they believe these technologies are acceptable solutions for India? (Bhattacharyya. S, 2010). However, as the need for domestic and commercial refrigeration and air conditioning increases in India, the end consumers, i.e. small and medium enterprise owners and residents need to be made aware of these technologies and their financial and environmental benefits in addition to the fact that they will help mitigate catastrophic climate change.

Various constraints, such as legislation for standards and policies, lack of funding and financial support, non-availability of technology and safety measures, interrupted supply of materials and equipment, in sufficient training for technicians, absence of markets and marketing of appliances using natural refrigerants and public perception of the natural refrigerant technologies (Bhattacharyya. S, 2010), hinder the growth of natural refrigerants on a large scale in India. However, with no formal legislation mandating the usage of natural refrigerants for air conditioning and refrigeration applications in the industrial, commercial and domestic sectors, the uptake of natural refrigerants becomes voluntary, hence has not been very significant.

Another key concern that acts as a barrier towards uptake of natural refrigerants is the flammability of hydrocarbon refrigerants, such as R290. Under such systems, additional mechanisms need to be installed that prevent refrigerant leakage and additional investments are required for carrying out safety engineering of these systems. This leads to increased overall costs to the end customer for the initial instalment as well as the maintenance of the systems. However, long-term benefits and awareness towards pay-back periods would help towards increasing uptake (ATMOsphere, 2010).

Slow uptake of natural refrigerants in India can be attributed to patent issues, amongst others. Technologies for production and use for some of them are patented; for example, technologies for producing HFO-1234yf and HFC-32 are patented by only a few companies like DuPont, ARKEMA, Honeywell and Daikin, which are all basically from developed countries (Paliwal A, 2012). Hence the adoption of these technologies is expensive and the necessary components and systems are not readily available within India. As per the statistical analysis of the Derwent World Patents Index, it was observed that geographically most of the patent documents for Solar Cooling Technologies were published for Europe, North America and Asia (WIPO, 2012). CSIRO has patented Solar Desiccant Air cooling System (Ford. J, 2010), which uses the desiccant material to dehumidify the incoming air. This dry air is then used in an evaporative cooler to bring down the room temperature below ambient temperature. Currently they are working to develop solar cooling technologies for food storage in India (CSIRO, 2016).

This adds transportation and opportunity cost to the already pricey components. The aforementioned and other prevalent issues lead to unfavourable market conditions that need attention. Additionally, conventional refrigerants such as, HCFCs and HFCs are readily available and the supporting technologies are tried, tested and inexpensive as compared to that of technologies using natural refrigerants, hence manufacturers and consumers have an inclination towards using these conventional technologies (Hydrocarbons21.com, 2011).

3.2 GHG-Efficiency Improvement: current or anticipated natural refrigerant uptake forces under BAU scenario and future opportunities

The successful uptake of natural refrigerants in India will be driven by various forces among various stakeholders. Increasing awareness towards natural refrigerants and cooling technologies is one of the most basic of these drivers. Uptake of natural refrigerants requires a strong network of awareness among various stakeholders, for example, government departments, suppliers and producers, non for profit companies and end – users in the commercial and residential sectors so that all can contribute in driving the market for these sustainable technologies.

Cost benefits and financial assistance for the adoption of natural refrigerant technologies and penalties for obsolete and conventional technologies can prove to be a very strong driver of natural refrigerant technology in India, as lack of financial assistance is one amongst the list of key barriers towards the acceptance of these technologies. Introduction of such initiatives should be accompanied by awareness raising efforts so as to ensure speedy implementation of the new technologies.

Developing and maintaining safety standards regarding toxicity, flammability, maintenance of components and procedures for refilling and reuse of refrigerants greatly influences the uptake of alternative substances in the refrigeration industry. These standards provide the manufacturer and servicing technicians with guidelines for handling, storage, transportation and disposal of refrigerants. To ensure successful implementation of these standards, technicians and servicing personnel need to be trained and certified. Certification and training of technical staff will equip them with servicing, energy optimization and maintenance capacity for the systems and provide assurance to the costumer of the safety of the natural refrigeration system (UNIDO, 2013).

The air conditioning market in India in the residential and commercial sectors has grown rapidly in the past few years and is expected to witness further growth in the years to come due to rise in average temperature and frequent heat waves as a result of climate change (IKI, 2015). The number of ACs sold in India in 2010 was 3.4 million and are expected to go up to 38 million in 2030. This will account to a total of 223 million ACs operating in India by 2030. As there are tremendous market opportunities in India in the air conditioning sector, the opportunities for using natural refrigerants is also huge. Godrej and Boyce is the first manufacturer in India to launch 1 TR and 1.5 TR air conditioners using R290 as refrigerant. These air conditioners are cost competitive and energy efficient than ACs of similar specifications using conventional refrigerants (Hydrocarbons21, 2012).

The technology of R290 is not limited to Godrej and is available to all the manufacturers willing to transition from manufacturing ACs using R22 to ACs using R290 as a refrigerant. The technology for producing R290 is not patented as propane is a naturally occurring gas and Indian manufacturers can implement and improve this technology at lower costs. ACs using R290 will emerge as a separate market segment and the servicing sector R290 ACs will also become stronger (Kar, 2014).

Along with phasing down of HFCs and other high GWP refrigerants, efforts are being made towards improving the energy efficiency of refrigeration and air conditioning systems to reduce the lifecycle cost, overall energy consumption, peak load consumption and GHG emissions. Transition to natural refrigerants and energy efficiency improvements of air conditioning and refrigeration systems can go hand in hand as most of the natural refrigeration systems provide higher energy efficiency. If the 2030 stock of room ACs in India are assumed to use low GWP refrigerants and high energy efficient systems, peak load reduction of 31 – 71 GW can be achieved and savings of GHG emissions of over 0.32 GT/year annually, which is around two times the savings expected from installing 100 GW during National Solar Mission (Shah. N et al., 2015).

According to a study carried out by the Centre for Science and Environment (CSE), only shifting to low GWP refrigerants will lead to 100 MT of CO_2e, whereas if energy efficiency improvement is made along with the shift in refrigerant, the savings are doubled. Increased uptake of natural refrigerants India will require capacity building of informal and formal servicing sectors which will increase the scope of the servicing industry to grow in terms of equipment support, recovery, reclamation and reuse of refrigerants (CSE, 2015).

3.3 Policy Support Recommendation

The uptake of natural refrigerants and sustainable cooling technologies in India has to adopt an integrated approach where all the stakeholders, beginning from consultants, developers, owners, architects, manufacturers, facility managers, project managers and contractors, should be engaged in the process to develop mutual trust. Their uptake is greatly dependent on the efficient and safe use of these natural refrigerants and available standards on safety, component design, instrumentation and control for respective technologies. In order to raise the consumption of Natural Refrigerants across various IPCC sectors of HVACR in India, few recommendations are mentioned below can be considered. According to UNIDO (2013), Bhattacharyya S (2010) and ATMOsphere (2010), following recommendations can be considered to raise the consumption of Natural Refrigerants across various IPCC sectors of HVACR in India.

Through training

- Online training schemes and better training material as regards to the properties, handling and storage of natural refrigerants should be provided including the videos demonstrating the best practices in the field. Circulation of free magazines to HVAC engineers and local HVAC associations can be done, to increase the consciousness on the upcoming technologies
- Mobile training can be made available with trainers travelling to the servicing garages and providing on-site training for technicians
- For effective implementation of training of trainer's scheme, refrigeration engineers training centers to be upgraded
- Incentives and recognition to be awarded to the technicians who are successfully following Best Practices in the domain of HVAC&R
- National certification scheme for technicians confirming completion of training course about real-life installation and maintenance of natural refrigerants equipment
- Handbooks on good servicing practices to be published and made easily accessible
- Existing engineering and technology curricula to be updated with Natural Refrigerant based technologies and their working principle
- New HVAC&R associations should be formed along with training bodies and certification schemes that would allow technicians to use their skills across the country and even outside would lead to a more flexible workforce, driving a faster market adoption of natural substances-based equipment

Through raising awareness

- Campaigns to be held for increasing awareness on long term benefits of natural refrigerants among public and manufacturers
- Introduction of natural refrigeration content in universities syllabus for undergraduate and graduate courses
- Risk awareness on flammability and toxicity of natural refrigerants should be increased among residential, commercial and industrial customers. The difference between actual risk and perceived risk should be made clear

Through government body support

- Government support to be provided in HVA&R sector for increasing the uptake of natural refrigerants by financial incentives, tax benefits, subsidy policies, bans and creating a competitive environment for natural refrigerant based technologies. At the same time, taxes can be imposed on the obsolete technologies for their accelerated phase down
- Market competition can be introduced in the area of, safety systems, supply of natural refrigerants and new technologies, R&D for new efficient systems
- Adaption of existing international standards or development of new standards for safety and use of the natural refrigerant technologies can prove to be supportive for overall increase in the consumption of these technologies

To overcome the barrier of low awareness level of Natural Refrigerants among stakeholders of Article 5 countries, stronger collaboration between developing countries in the same regional networks can be established with the help of institutes. Further, multidisciplinary working groups can be formed to evaluate all the aspects relating to selection of new technologies and effective knowledge transfer from developed to developing countries. Harmonization of global HCFC frameworks with local rules will provide clear guidelines on HCFC phase out process help build the policy frameworks to expedite the leapfrogging to low GWP alternatives.

References

1. Achrnews.com. (2004). *CO2 As Refrigerant: The Transcritical Cycle*. Available at: http://www.achrnews.com/articles/94092-co2-as-refrigerant-the-transcritical-cycle

2. ACREX, (2016). *Infinite opportunities and increasing demands*. Available at: http://www.acrex.in/pressRelease.html

3. AESC, (n.d.). *Tips: Evaporative Cooling Technologies*. AESC-Energy Solutions for Changing World. Available at: http://www.aesc-inc.com/Evaporative%20Cooling%20Technologies_Tip.pdf

4. A-Gas, (2005). *Ammonia- Anhydrous Material Safety Data Sheet*, A-Gas Australia.

5. AIRAH, (2007). *Natural Refrigerants Case Studies.* [online] Australian Institute of Refrigeration, Air Conditioning and Heating. Available at: https://www.airah.org.au/imis15_prod/Content_Files/TechnicalPublications/natural-refrigerants-case-studies.pdf
6. Ansbro. J, (n.d.). *Packaged Ammonia Chillers with Variable Frequency Drives.* Johnson Controls.
7. ASHRAE, (2008). *ASHRAE Standard: Designation and Safety Classification of Refrigerants*. American Society of Heating, Refrigerating and Air-Conditioning Engineers.
8. ASHRAE, (2012). *Position Document on Refrigerants and their Responsible Use*. ASHRAE, p.6.
9. ATMOsphere, (2010). *How To Bring Natural Refrigerants Faster To Market*. Brussels: ATMOsphere. Available at: http://www.atmo.org/presentations/files/72_ATMOsphere-report.pdf
10. Austin, B. and Sumathy, K. (2011). *Transcritical carbon dioxide heat pump systems: A review. Renewable and Sustainable Energy Reviews*, 15(8), pp.4013-4029.
11. Baskaran, A. and Mathews, K. (2012). *A Performance Comparison of Vapour Compression Refrigeration System Using Eco Friendly Refrigerants of Low Global Warming Potential*. International Journal of Scientific and Research Publications. Available at: http://www.ijsrp.org/research-paper-0912/ijsrp-p0906.pdf.
12. Bhattacharyya, S. (2010). *NATURAL REFRIGERANTS – The Indian Perspective*. Available at: http://www.atmo.org/presentations/files/38_SouvikBhattacharyya_IIT_NatRef-India.pdf.

13. Bhushan. C, (2015). *Getting the world off the Chemical Treadmill: A per capita convergence framework for an ambitious phase-down of HFCs under the Montreal Protocol*. 1st ed. [ebook] New Delhi: Center of Science and Environment, p.Page 5. Available at: http://conf.montreal-protocol.org/meeting/oewg/oewg-36/pubs/English/Getting%20the%20world%20off%20the%20chemical%20treadmill-CSE.pdf

14. Borgford-Parnell. N et al, (2015*). Phasing Down the Use of Hydrofluorocarbons (HFCs).* Available at: http://2015.newclimateeconomy.report/wp-content/uploads/2015/10/Phasing-down-HFCs_final_web.pdf.

15. Carbajal. P et al, (2009). *HFCs: A growing threat to the climate*. Greenpeace. Available at: http://www.greenpeace.org/international/Global/international/planet-2/report/2009/12/hfcs-a-growing-threat-to-the-climate.pdf.

16. Chaturvedi, V. (2015). *The Costs of Climate Change Impacts for India*. New Delhi: CEEW. Available at: http://ceew.in/pdf/ceew-cost-of-climate-change-impacts-for-india-2-apr-5.pdf
17. CII, (2014). *Micro, Small & Medium Enterprises Issues & Recommendations*, May 2014
18. CII, (n.d.). *Make in India and the Potential for Job Creation*. [online] Confederation of Indian Industry (CII). Available at: http://www.ies.gov.in/pdfs/make-in-india-oct15.pdf
19. Colbourne, D. and Usinger, J. (2015). *Natural Refrigerants- Safe, Efficient and Reliable use as Alternatives to HFC*. [online] GIZ Proklima. Available at: http://www.unep.org/ozonaction/Portals/105/documents/events/MOP27/03c%20HA%20Presentation%20GIZ.pdf.

20. Colbourne. D, (2011*). Hydrocarbon Refrigerants for Room Air Conditioners*. (2011). GIZ Proklima.

21. Cooling India, (2013), *Direct Structure Colling- An Analysis*. Cooling India, 2013. Web. Vol. 8 , No-10. Available at: https://drive.google.com/file/d/0B7zX8HIEvC6rbHVWOVYyNFN6U2M/view
22. Cox, N. (2011). *Air Conditioners/Refrigerants - Alternative Refrigerants for High Ambient Temperature Conditions*. Earthcare Products Limited.
23. CSE, (2015). *HFC management in Article 5 countries*. Centre for Science and Environment.
24. Csiro.au. (2016). *Solar cooling - CSIRO*. [online] Available at: http://www.csiro.au/en/Research/EF/Areas/Solar/Solar-cooling.

25. Danfoss, (2016). *Ammonia as Refrigerant | Ammonia Cooling in Refrigeration | Danfoss*. Available at: http://industrialrefrigeration.danfoss.com/refrigerants/ammonia/why-ammonia/

26. Danfoss, (n.d.). *High efficient heat reclaim with CO2*. [online] danfoss.com. Available at: http://www.danfoss.com/nr/rdonlyres/8d443cec-8dfc-476b-87a2-3895c66ae013/0/highefficientheatreclaimwithco2.pdf

27. Datta, A. (2014). *India demands technology transfer for HFCs phase out*. [online] The Hindu Business Line. Available at: http://www.thehindubusinessline.com/economy/policy/india-demands-technology-transfer-for-hfcs-phase-out/article6618474.ece

28. Devotta. S et al, (n.d.). *Refrigeration. IPCC/TEAP Special Report: Safeguarding the Ozone Layer and the Global Climate System*. Available at: https://www.ipcc.ch/pdf/special-reports/sroc/sroc04.pdf.

29. DHI, (2014). *Annual report 2013-14,* Ministry of Heavy Industries and Public Enterprises, Government of India. Available at: http://dhi.nic.in/writereaddata/UploadFile/dhi_annual_rep_eng_1213.pdf

30. EIA, (2015). *EU F-Gas Regulation Handbook: Keeping Ahead of the Curve as Europe Phases Down HFCs*. [online] Environmental Investigation Agency. Available at: https://eia-international.org/wp-content/uploads/EIA-F-Gas-Regulation-Handbook.pdf.

31. Ernst & Young LLP and RAI, (2014). *Pulse of Indian retail market: A survey of CFOs in the Indian retail sector*. Ernst & Young LLP and Retailers Association of India. Available at: http://www.rai.net.in/EY-RAI_Pulse_of_Indian_retail_market_Final.pdf

32. FICCI & PWC, (2015). *India: Surging to a smarter future*. PWC. Available at: https://www.pwc.in/assets/pdfs/publications/2015/india-surging-to-a-smarter-future.pdf

33. Ford. J, (2010). *New materials improve solar air conditioning*. Available at: https://www.theengineer.co.uk/new-materials-improve-solar-air-conditioning/.

34. Garg, A et al, (2015). *Climate Change and India: Adaptation Gap (2015) - A Preliminary Assessment.* Working paper of Indian Institute of Management Ahmedabad (IIMA) W.P. No. 2015-11-01. Indian Institute Of Management Ahmedabad. Available at: http://www.iimahd.ernet.in/assets/snippets/workingpaperpdf/10071603592015-11-01.pdf.

35. GIZ Proklima, (n.d.). *Environmental impact of the refrigeration and air conditioning sectors*. GIZ Proklima. Available at: http://www.green-cooling-initiative.org/data/user_upload/GCI-factsheet-refrigerants.pdf

36. GreenPeace, (n.d.). *Natural Refrigerants: The solution*. GreenPeace International. Available at: http://www.greenpeace.org/international/Global/international/planet-2/report/2009/5/natural-refigerants.pdf

37. Gupta, J. (2014). *Migration, the everyday face of climate change*. India Climate Dialogue. Available at: http://indiaclimatedialogue.net/2014/03/17/migration-the-everyday-face-of-climate-change/.

38. Heaney. C et al, (2007). *Natural Refrigerants Case Studies*. Australian Institute of Refrigeration, Air Conditioning and Heating. Available at: https://www.airah.org.au/imis15_prod/Content_Files/TechnicalPublications/natural-refrigerants-case-studies.pdf.

39. Hydrocarbons21, (2012). *Indian producer has sold 3,000 R290 AC units that meet 2016 efficiency standards*. Hydrocarbons21.com. Available at: http://www.hydrocarbons21.com/articles/3395/indian_producer_has_sold_3_000_r290_ac_units_that_meet_2016_efficiency_standards.

40. Hydrocarbons21.com. (2011). *Project to further the uptake of hydrocarbons in India and beyond.* [online] Available at: http://www.hydrocarbons21.com/articles/2670/project_to_further_the_uptake_of_hydrocarbons_in_india_and_beyond.

41. IIAR, (n.d.). *Ammonia: Natural Refrigerant of Choice*. An IIAR Green Paper. Available at: http://ammonia21.com/assets/paper/file/iaar-green-paper-ammonia.pdf

42. IIF, (n.d.). *Classification of Refrigerants*. Paris: Institut International du Froid. Available at: http://www.iifiir.org/userfiles/file/webfiles/summaries/Refrigerant_classification_EN.pdf.

43. IITK, (n.d.). *Refrigerants*. Lesson 26. IIT Kharagpur: NPTEL. Available at: http://nptel.ac.in/courses/112105129/pdf/R&AC%20Lecture%2026.pdf.

44. IKI, (2015). *Keeping Cool in India*. International Climate Initiative. Available at: https://www.international-climate-initiative.com/en/news/article/'keeping_cool_in_india'/

45. IPCC Fifth Assessment Report, (2014). Global Warming Potentials. GHG Protocol, p.Page 2.

46. Ishrae.in. (2016). *ISHRAE - Indian Society of Heating Refrigerating and Air Conditioning Engineers.* [online] Available at: http://ishrae.in/newsdetails/ACREX-India-2016-Poised-to-Beat-Previous-Records/421.

47. James. R et al, (1997). *Energy and Global Warming Impacts of HFC Refrigerants and Emerging Technologies*. Tennessee: Oak Ridge National Laboratory. Available at: https://www.epa.gov/sites/production/files/documents/Energy_and_Global_Warming_Impacts_of_HFC_Refrigerants.pdf.

48. Kar. A. (2014). *Energy Efficient, Climate Friendly Refrigerants for Hot and Humid India: Moving into the Future*. NRDC. Available at: https://www.nrdc.org/experts/avinash-kar/energy-efficient-climate-friendly-refrigerants-hot-and-humid-india-moving-future.
49. Koban. M, (2016). *HFO-1234yf Low GWP Refrigerant LCCP Analysis*.
50. KPMG, (2014). *The new wave Indian MSME: An action agenda for growth*. KPMG. Available at: https://www.kpmg.com/IN/en/IssuesAndInsights/ArticlesPublications/Documents/The%20new%20wave%20Indian%20MSME_Low%20Res.pdf
51. Kunche. V, n.d. *Solar Absorption Chiller Technology Presentation*. First ESCO India Pvt Ltd.
52. Lindborg A, (2005). *Evaluating progress towards developing safe, cost-effective ammonia cooling systems;* Alternative Cooling Technologies conference presentation, London.

53. Maté. J and Papathanasopoulos. C, (2012). *Cool Technologies: Working without HFCs*. Example of HFC-Free Cooling Technologies in various Industrial Sectors. Greenpeace. Available at: http://www.greenpeace.org/international/Global/international/publications/climate/2012/Fgases/Cool-Technologies-2012.pdf.

54. McKinsey and Co., (2009). *Environmental energy sustainability: An approach for India*. McKinsey and Co.
55. McKinsey, (2009). *Building India: Accelerating Infrastructure Projects*. McKinsey.
56. McKinsey, (n.d.) *Building India: Transforming the nation's logistics infrastructure*, McKinsey

57. Ministry of Environment Denmark, (2012). *Low GWP Alternatives to HFCs in Refrigeration*. 1st ed. [ebook] Strandgade: Environmental Protection Agency, Strandgade. Available at: http://www.unep.org/ozonaction/ecanetwork/Portals/138/ECA%202012/Announcements/Low%20GWP%20Alternatives%20to%20HFCs%20in%20Refrigeration.pdf

58. MoEF&CC, (2015). *HFC Phasedown: Indian Proposal*. Government of India.
59. MoF, (2014), *Economic Survey 2013-14*. Ministry of Finance, Government of India. Available at: http://indiabudget. nic.in/survey.asp
60. MSDE, (2015). *Pradhan Mantri Kaushal Vikas Yojana (PMKVY).* Ministry of Skill Development and Entrepreneurship. Government of India. Available at: http://www.skilldevelopment.gov.in/assets/images/PMKVY%20Scheme%20booklet.pdf.

61. MSDE, (2016). *Introduction: Directorate General of Training (DGT)*. Ministry of Skill Development and Entrepreneurship. Available at: http://dget.nic.in/content/innerpage/introduction-sdis.php

62. MSME, (2014). *Annual Report 2013-14, Ministry of Micro, Small and Medium Enterprise: Government of India.* Available at: http://msme.gov.in/WriteReadData/DocumentFile/ANNUALREPORT-MSME-2013-14P.pdf

63. Mundie. I, (2005). *Exploring the extent to which ammonia is viable as a widespread commercial alternative to HFCs*. Alternative Cooling Technologies conference presentation.
64. NRDC, (2013). *Cooling India with Less Warming: The Business Case for Phasing Down HFCs in Room and Vehicle Air Conditioners*. NRDC, CEEW, TERI, IGSD. Available at: https://www.nrdc.org/sites/default/files/air-conditioner-efficiency-IP.pdf
65. NRDC, (2014*). Frequently Asked Questions on Cooling India with Less Warming: The Business Case for Phasing Down HFCs.* NRDC, CEEW, TERI, IGSD. Available at: https://www.nrdc.org/sites/default/files/air-conditioner-efficiency-FS.pdf
66. NRDC, (n.d.). *Air Conditioners with Hydrocarbon Refrigerant – Saving Energy while Saving Money.* NRDC, TERI, CEEW, IGSD.
67. Paliwal, A. (2012). *Developed nations want India to leapfrog to a technology which even they have not accepted*. Available at: http://www.downtoearth.org.in/interviews/developed-nations-want-india-to-leapfrog-to-a-technology-which-even-they-have-not-accepted--39639.
68. Panda, A. (2010). *Climate Refugees: Implications for India. Economic & Political Weekly*. Available at: http://alofatuvalu.tv/FR/12_liens/12_articles_rapports/refugee_india.pdf.

69. Pearson. S. F, (n.d.). *New, Natural and Alternative Refrigerants*. 1st ed. [ebook] Star Refrigeration Limited,

p.Page 2. Available at: https://www.epa.gov/sites/production/files/documents/New_Natural_and_Alternative_Refrigerants.pdf

70. Phadke.A et al, (2014). *Avoiding 100 New Power Plants by Increasing Efficiency of Room Air Conditioners in India: Opportunities and Challenges*. 7th International Conference on Energy Efficiency in Domestic Appliances and Lighting. Coimbra: Ernest Orlando Lawrence Berkeley National Laboratory. Available at: http://eetd.lbl.gov/sites/all/files/lbnl-6674e.pdf
71. Qureshi, A. and Bhatt, S. (2014*). Comparative Analysis of Cop Using R134a & R600a Refrigerant in Domestic Refrigerator at Steady State Condition*. International Journal of Science and Research. Available at: http://www.ijsr.net/archive/v3i12/U1VCMTQ2MDM%3D.pdf.
72. Rajadhyaksha. D, 2013. *Development and Handeling of HC Airconditioners- The Godrej Experience.* Bangkok Technology Conference.
73. Ram, N. (2014). *HVAC Industry: Current challenges & future market growth - PROJECT VENDOR*. [online] Project Vendor. Available at: http://projectvendor.com/hvac-industry-current-challenges-future-market-growth/
74. Refrigerants.danfoss.com. (2016). CO_2 | Natural Refrigerants | Energy Efficiency | Danfoss. Available at: http://refrigerants.danfoss.com/co2/

75. Refrigerants.danfoss.com. (2016). *Refrigerants for Lowering the GWP: Ammonia*. Available at: http://refrigerants.danfoss.com/ammonia/

76. Reportlinker.com. (2014*). World Commercial Refrigeration Equipment Market - market research report*. [online] Available at: http://www.reportlinker.com/p0701867-summary/World-Commercial-Refrigeration-Equipment-Focus-report-Freedonia.html

77. Rolfsman, L. (2005). Alternative Cooling Technologies conference presentation; Alternative Cooling Technologies conference presentation.

78. Satry. G, 2012. *First Radiant Cooled Commercial Building in India – Critical Analysis of Energy, Cost and Comfort*. Bangalore. Green Initiatives Infosys Ltd

79. Sethi, N. (2014). *Refrigerant gases, climate change and India.* [online] Business-standard.com. Available at: http://www.business-standard.com/article/economy-policy/refrigerant-gases-climate-change-and-india-114112100024_1.html
80. Shah. N et al, (2015). *Benefits of Leapfrogging to Superefficiency and Low Global Warming Potential Refrigerants in Room Air Conditioning*. Lawrence Berkeley National Laboratory. Available at: http://eetd.lbl.gov/sites/all/files/lbnl-1003671_0.pdf.
81. Shoeb. S. M, 2013. *Thermal Comfort by Direct Structure Cooling: Viability of DSC for Indian Climate*. Master Thesis. CEPT University

82. Singh. R, Agrawal. A, (2013). *Performance Analysis of Water (R718) As a Refrigerant in Medium Range Temperature*. International Journal of Emerging Science and Engineering (IJESE), Vol 1(Issue 09). Available at: http://www.ijese.org/attachments/File/v1i9/I0396071913.pdf.

83. Smartcitiesindia.com. (2016). *Smart Cities India 2016 - Smart Water and Waste Management Exhibitor Profile*. Available at: http://www.smartcitiesindia.com/exhi-pro.aspx
84. Spatz. M and Minor. B, (2008). *HFO-1234yf A Low GWP Refrigerant For MAC Honeywell / DuPont Joint Collaboration*.
85. Spross, J. (2014). *India, China, And Other Developing Countries Agree To Talks To Phase Out A Potent Greenhouse Gas.* [online] ThinkProgress. Available at: http://thinkprogress.org/climate/2014/11/21/3595635/india-china-hfc-agreement/

86. Sustainability Victoria, (2009). *Energy Efficiency Best Practice Guide: Industrial Refrigeration*. Sustainability Victoria.

87. Swep.net. (2016). *5.4 Refrigerant types - SWEP*. Available at: http://www.swep.net/refrigerant-handbook/5.-refrigerants/sd4/

88. T. V. Padma, (2015). *India takes baby steps towards HFC phase-out.* [online] Available at: http://indiaclimatedialogue.net/2015/07/09/india-takes-baby-steps-towards-hfc-phase-out/

89. The New Building Institute, (1998). *Absorption Chillers: Advanced Design Guideline Series*. Available at: http://web.stanford.edu/group/narratives/classes/08-09/CEE215/ReferenceLibrary/Chillers/AbsorptionChillerGuideline.pdf.

90. UNEP, (2009). *Proposed Amendment to Montreal Protocol*. Geneva: Federated States of Micronesia and Mauritius.

91. UNEP, (2014). *Low-GWP Alternatives in Commercial Refrigeration: Propane, CO2 and HFO Case Studies*. United Nations Environment Programme. Available at: http://www.unep.org/ccac/portals/50162/docs/Low-GWP_Alternatives_in_Commercial_Refrigeration-Case_Studies-Final.pdf.

92. UNIDO, (2013). Natural Solutions For Developing Countries. United Nations Industrial Development Organization. Available at: https://www.unido.org/fileadmin/user_media_upgrade/What_we_do/Topics/Multilateral_environmental_agreements/GUIDE-UNIDO-natural-substances-2013-small.pdf

93. US EPA, (2007). *Air Emissions*. US EPA. Available at: http://www.fe.doe.gov/programs/gasregulation/authorizations/2012_applications/Sierra_Club's_MOI_Exhibits_/69_EPAAi_Emissions.pdf.

94. Velders et al. (2009). *The large contribution of projected HFC emissions to future climate forcing.* Proceedings of the National Academy of Sciences, 106(27), pp.10949-10954. Available at: http://www.pnas.org/content/106/27/10949.full.

95. WHO, (2003). *Climate change and human health: RISKS AND RESPONSES*. Geneva: World Health Organisation. Available at: http://www.who.int/globalchange/publications/climchange.pdf

96. WIPO, (2012). *Patent Landscape Report on Solar Cooling Technologies*. World Intellectual Property Organization. Available at: http://www.wipo.int/edocs/pubdocs/en/patents/948/wipo_pub_948_3.pdf.

97. Witt. M, (n.d.). *Natural refrigerants: current developments and trends*. Eurammon. Available at: http://www.eurammon.com/sites/default/files/attachments/eurammon_background-article_energy-efficiency_engl.pdf.